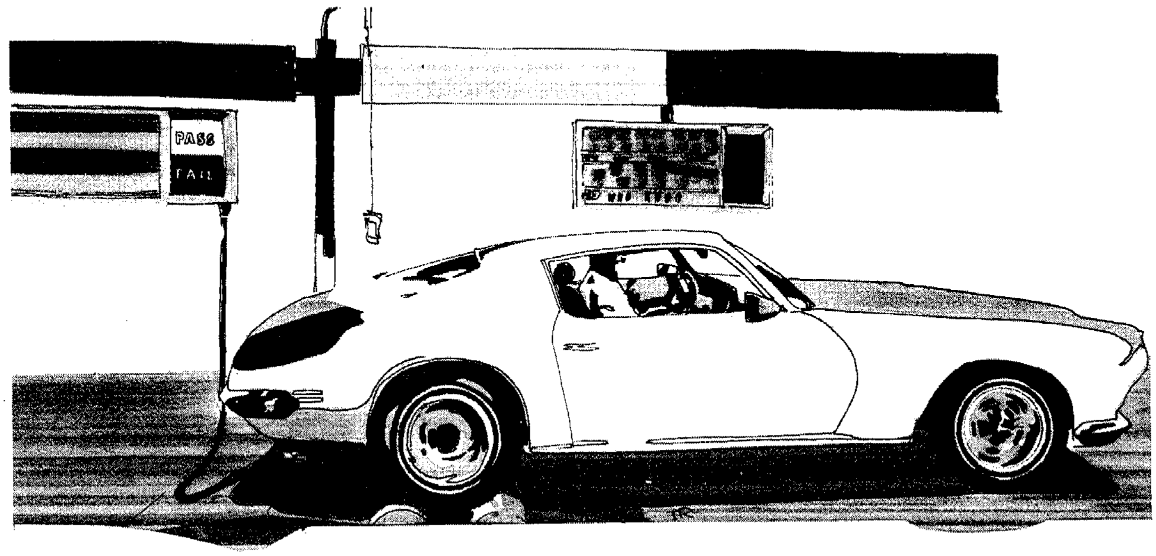
AUTOMOTIVE EXHAUST EMISSION STANDARDS



VOLUME II
TECHNICAL ANALYSIS

FINAL REPORT

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FOR

STATE OF CALIFORNIA
AIR RESOURCES BOARD

TRW TRANSPORTATION & ENVIRONMENTAL OPERATIONS

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The results and conclusions are based on the latest, internally consistent emissions data base collected between 1970 - 1972. The extent to which these data are not representative of the vehicle population in the Los Angeles area, however, could have a significant impact on the resultant conclusions and recommendations. In particular, the lack of available data on 1973 - 1974 vehicles and on in-use fleet retrofitted vehicles may, to some extent, affect the results developed in this study.

PREFACE

This report discusses the establishment of loaded mode emission standards for the proposed California vehicle inspection and maintenance program. Development of these standards was undertaken in recognition of the role of exhaust emissions in the overall problem of air pollution for the South Coast Air Basin. A cost-effective approach was taken in designing emission standards for the vehicle population. Here, the interactions between modal emissions, mass emission and vehicle characteristics were evaluated in arriving at a set of preferred emission criteria. Hopefully, there standards will play a key part in improving air quality for the region.

ACKNOWLEDGEMENTS

TRW would like to acknowledge the efforts extended by the California Air Resources Board in support of the project. The contributions of Messrs. G. C. Hass, Joe Calhoun and Ray Engles were of particular significance.

Additionally, TRW wishes to acknowledge the fine assistance offered by Clayton Manufacturing in the development of procedures for evaluating the merits of more stringent re-test standards. The support of Messrs Ed Cline, Frank Hartman and Lee Tinkham in this regard was timely and substantive.

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1.0 CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations presented herein highlight the results from the emission standards program for the California Air Resources Board. A more definitive set of study observations and results can be found in subsequent sections of this report.

- An initial vehicle rejection rate of approximately 30 percent yields the most cost-effective results for a loaded mode inspection and maintenance program.

- The average emission reduction (CVS measurements) for a 30 percent rejection rate are 9.0%, 7.9% and -0.9% for HC, CO and NOx, respectively. These performance estimates do not include the impact of engine deterioration. The reduction potential for 1971-1974 vehicles will tend to increase with use and consequently these overall estimates of emission reduction are conservative.

- Nearly 15 percent of those vehicles which undergo maintenance for failing the initial inspection will fail the subsequent re-test (i.e., approximately 5 percent of the total population).

- The emission standards have been designed with an emphasis on HC reductions. This is in keeping with the reactive hydrocarbon-photochemical nature of the air pollution problem for the South Coast Air Basin.

- The influence of engine deterioration, owner tampering and unreliable repair have not been considered directly in establishing the emission standards. The existence of these factors could have a substantial effect on resultant emission reductions for a given rejection level. In general, more severe standards (i.e., failure of a larger percentage of the population) will be required to achieve a comparable emission reduction level in the presence of these elements.

- No practical procedures exist at the present time for establishing NOx emission standards for pre-1966 (non-retrofited vehicles) and 1966 - 1970 vehicles. This situation can be attributed to the inverse relationship between CO control and NOx control and the lack of effective emission modal diagnostic signatures.

- Classifications are required to adequately describe the vehicle population in consistent terms. Applying one set of standards to the entire population will lead to ineffective and socially regressive results.

- The most descriptive vehicle population classification scheme was found to include age and engine size (i.e., number of cylinders). In particular, three age classifications (pre-1966, 1966 - 1970 and 1971 - 1974) and three engine size groups (4, 6 and 8 cylinders) appear most descriptive. Using this engine classification scheme helps maintain a high level of program efficiency because of the relative ease in identifying the number of cylinders per vehicle.

- While different combinations of engine displacement groupings were found most descriptive for each age category, for operational consistency a uniform set was established. This scheme separates the vehicle population into 4 cylinders and 6 or 8 cylinder classes for the three age groups. The impact of their simplification on emission reduction effectiveness was found to be substantially less than the potential effects of engine deterioration, owner tampering or unreliable repair. Furthermore, it will have a positive influence on reducing operational errors at the inspection station.

- The analysis yielded loaded mode emission standards which reject approximately equal numbers among the various classification elements. These results tend to minimize the social regressiveness of the program while at the same time providing cost-effective emission reduction performance.

- Different levels of vehicular rejection may occur locally as a result of implementing the standards on a region wide basis. That is, the spatial distribution of the vehicle population is not uniform and consequently different rejection rates can be expected as a function of station location.

- A total of 36 different standards have been established for various segments of the vehicle population. This includes three age groups, two engine displacement types, two emission and three measurement modes, (3x2x2x3 = 36). In addition, separate standards have been developed at idle for air pump equipped vehicles and non-air pump equipped vehicles. A NOx screening standard on 1971 - 1974 vehicles also has been recommended.

- The developed loaded mode emission standards were designed to identify those vehicles where maximum emission reductions (as measured in CVS units) could be achieved for a given rejection level. The process considered the potential interactions between modes, emissions and vehicle characteristics in arriving at the preferred standards. This approach insures the establishment of the most cost-effective set of emission standards.

- The data base used in this study contained vehicles that underwent comprehensive engine repair. Those vehicles failing a particular emission mode (e.g., idle) had all detected malfunctions repaired as opposed to repair of only those items causing failure.

- Modal emission rejection levels will tend to decrease over time as more vehicles receive corrective maintenance. A periodic updating of the emission standards may be necessary to achieve a consistent level of emission reduction from the vehicle population.

- An interim set of loaded mode emission standards should be established during the initial phase of the basin wide demonstration program. This will permit adequate time to check out and update basic procedural and system operations.

- Emission data should be developed to better characterize NOx emissions from vehicles with failed NOx control systems. Test data should also be collected for 1973 - 1974 vehicles with and without air pumps.

- An ongoing emission measurement program is required to obtain the data necessary to establish emission standards for post-1974 vehicles. The surveillance system should include both CVS and loaded mode measurements with particular emphasis on NOx emissions and diagnostic data.

- Because of the multiplicity of emission control systems for 1971 - 1974 vehicles, a functional or diagnostic inspection approach may be, in the limit, more cost-effective than an emission inspection test.

- The developed standards may not be applicable to those vehicles which have been retrofitted with emission control devices (pre-1966-VSAD, 1966 - 1970 - EGR). Separate standards were not developed for these classes of vehicles because of the lack of empirical data. It is recommended that test data be collected on these vehicles as an integral part of the inspection program.

2.0 INTRODUCTION

California Senate Bill 479 requires the Department of Consumer Affairs, in concert with the Highway Patrol and the Air Resources Board (ARB) to design and adopt a program for the mandatory inspection and maintenance of all motor vehicles within the six county Southern California Air Basin. Under this act, it is the responsibility of the ARB to set the emission standards for use in the inspection program. This study, requested by the legislature, is designed to establish a comprehensive set of key mode emission standards in support of the overall inspection program.

A program of vehicular inspection and maintenance is, in principle, a simple and direct near-term approach for controlling exhaust emissions from the vast majority of the automotive population. This control program can be accomplished by employing any one of a number of basic alternatives, e.g., idle, loaded, hybrid. In general, it requires a periodic inspection of each vehicle in the population to determine whether or not it conforms to existing emission standards or engine specifications. Those vehicles failing the inspection procedure are required to undergo subsequent maintenance to return their operation to acceptable levels. All cars, both old and new, feel the direct impact of their control approach. A vehicular inspection program represents a flexible strategy relative to the problem of emission control for not only is it a separate alternative in itself, but it can be used in conjunction with the introduction of advanced emission control systems.

The use of emission tests, such as a loaded mode, to determine the extent of engine maladjustments and malfunctions is desirable from two prospectives. First, the approach tends to have substantially lower costs than the so-called functional tests; and, second, it provides some indication of vehicular emission levels. Unfortunately, an emission inspection is confronted by both errors of omission and commission which, if not properly designed for, can yield ineffective results. The current study has been designed to consider both classes of errors in establishing effective emission standards.

One of the basic elements and major impact variables influencing program design is the inspection criteria. For a loaded mode oriented inspection, a number of unique standards must be established for the various combinations of modes, emission species, and vehicle types, e.g., idle HC for pre-1966 four cylinder vehicles. These inspection standards, in effect, will specify the level of vehicle rejection which in turn will determine the resultant emission reductions and associated costs.

Typically, higher rejection rates lead to greater emission reductions at higher program costs while lower rates yield smaller reductions at somewhat reduced costs. The establishment of "optimal" key mode emission standards requires an assessment of both reduction effectiveness and costs.

TRW has adopted primarily an empirical approach in establishing optimal emission standards for the ARB. The methodological approach consists of the following steps:

- Collection and management of emission and engine diagnostic data sets
- Statistical pooling and analysis of data sets

- Development of vehicle population classification system
- Design of key mode emission standards
- Cost-effective analysis of emission standards

The task of developing optimal standards is complicated by the large number of potential interactions among test modes, emission species and vehicle characteristics. Designing key mode standards requires a careful evaluation of these elements in conjunction with emission reductions and costs. For this study the problem was extended to include consideration of: 1) re-test standards, 2) NOx standards and procedures, 3) methods for establishing standards for post-1974 vehicles, 4) vehicle exemption procedures. TRW's analysis has resulted in a system of flexible yet cost-effective key mode emission standards for application in the South Coast Air Basin.

3.0 TECHNICAL ANALYSIS OF EMISSION STANDARDS

3.1 OVERVIEW

This section describes the basic methodological approach used in establishing the loaded mode standards. Although the proposed California program may include procedures other than loaded mode (e.g., direct engine analysis) they were not evaluated during the course of this study. The primary objective of this analysis was to develop an optimal set of loaded mode standards for various segments of the vehicle population. Specific diagnostic analyses are presented, however, in the case of NOx and post-1974 emission control systems.

The complex nature of defining effective loaded mode standards required the application of a comprehensive data management and analysis approach.. Basically, the analysis consisted of evaluating emission signature measurements taken from over 3,000 vehicles operating in the Los Angeles area. The data base was developed from previously conducted experiments on a sample representative of the current vehicle fleet. This approach permitted an indepth examination of relevant key mode, CVS and Engine Diagnostic data from both inspected and maintained vehicles.

The methodology utilized in establishing the loaded mode standards was predicated on the following ground rules:

1. Developing emission standards that maximize the cost-effectiveness of HC, CO, and NOx reductions for a given level of vehiclular rejection.

2. Developing effectiveness results which are computed in terms of CVS mass emission reduction.

3. Developing emission standards that tend to minimize the social regressiveness nature of the program with respect to individual segments of the population (e.g., large failure rates for uncontrolled versus low failure rate for post 1970 vehicles).

4. Developing emission standards that are effective and comprehensive yet that are readily usable in an operational setting (i.e., minimizing the number of unique standards).

Clearly several of these ground rules are not necessarily compatible, and consequently the methodology was designed to perform the required tradeoffs. The tradeoff analysis focused on evaluating the basic interactions between modes and species in arriving at effective key mode standards. In fact, the study develops an optimal set of standards for various levels of vehicular rejection, (e.g., 0 through 100 percent) and identifies the optimal rejection rate.

In addition to these elements the methodology had to be sensitive to a number of technical considerations concerning the characteristics of the vehicle population. Among the more significant were:

- Engine and emission diagnostics
- Composition of the vehicle fleet
- Vehicle characteristics (e.g. age and displacement)
- Emission control technology

Each of these factors were assessed in detail in establishing the key mode standards.

Figure 3 - 1 presents an overview schematic of the methodological approach used in carrying out the study. The analysis began with the establishment of a set of program ground rules and requirements. Next, emission and engine diagnostic data was collected and synthesized. Detailed statistical pooling and analysis procedures were then performed to develop the largest internally consistent data base. This

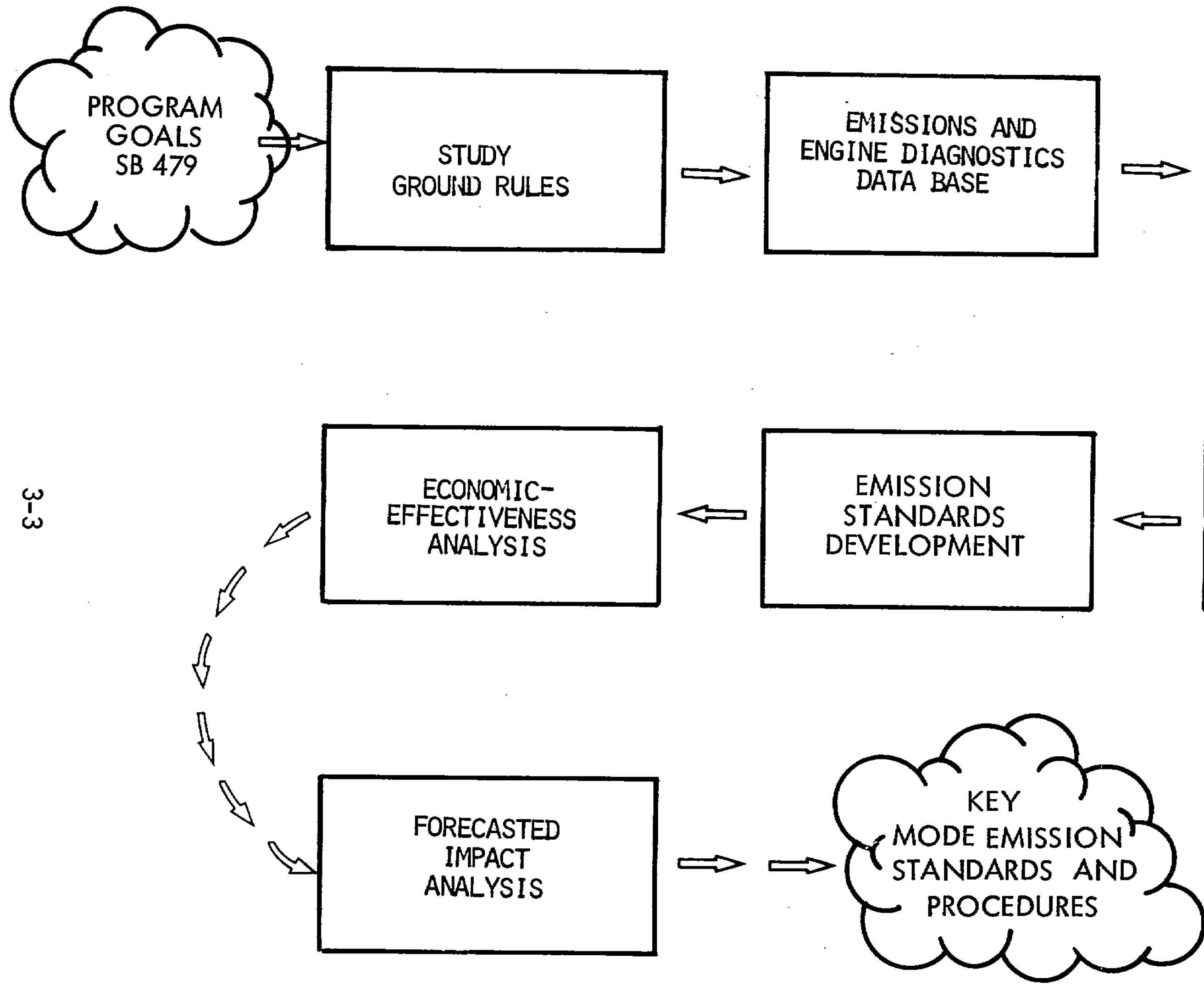

Figure 3-1. Methodological Overview

data base formed the framework for designing the vehicle classification scheme. Here, the vehicle population was partitioned into segments each with similar emission characteristics. Regression estimates were also developed for relating various vehicular components e.g., weight and engine size. A set of preliminary loaded mode emission standards were developed for each of the individual vehicle subfleets. These standards were evaluated using conventional cost-effectiveness analysis. Finally, the impact of the proposed standards was forecasted through 1978. The results of these analyses led to the finalization of both standards and procedures.

3.2 EMISSION AND ENGINE DIAGNOSTIC DATA BASE

Several sets of vehicular emissions and engine diagnostics were evaluated for potential use in this study. The reason for utilizing a large data base stems from the need to partition the vehicle fleet into a number of sub-populations which can be characterized with sufficient statistical accuracy. Table 3-1 summarizes the relevant characteristics of each data base. All of the listed sets were developed from vehicles operating within the South Coast Air Basin. The table depicts the basic data required for systematically developing a set of loaded mode emission standards. As can be seen, there are numerous voids in this data matrix which tend to confound the problem of obtaining a representative sample set. The following paragraphs present highlights of each of the data sets listed in the table*.

*A detailed listing of the TRW data base can be found in Appendix A.

TABLE 3-1

ENGINE AND EMISSION DATA BASE

	Source	Sample Size	Engine Diagnostics	CVS	Idle	Key Mode Low Cruise	High Cruise	Before/After Tuning	Vehicle Characteristics
1.	TRW CAPE-13 (1972)	450	A/F RPM Timing Misfire AP Heat Riser Valve NOx Control PCV Choke AC	HC CO NOx	HC CO NOx	HC CO NOx	HC CO NOx	Pre-Post Deterioration	65-72 Make Weight Cubic Displacement EM/AR
2.	ARB Surveil-lance	2,000	A/F AC	NONE	HC CO	NONE	NONE	Pre	65-74 Cubic displacement EM/AR
3.	ARB Advanced Vehicles	160	A/C	HC CO	NONE NOx(some)	NONE	NONE	Retrofit Deterioration	1966-1973 Make (some) No. cylinders(some) Cubic Displacement
4.	Northrop/Olson (1970)	1,500	AP A/F RPM	NONE NOx(some)	HC CO	HC CO	HC CO	Pre-Post	65-70 Make EM/AR Cubic displacement No. cylinders
5.	AAA	100	Timing A/F	NONE	NONE	NONE	NONE	Post	1972 Make Weight Cubic displacement No. cylinders
6.	EPA Pre-Controlled	100	A/F	HC CO NOx	HC CO	HC CO	HC CO	Pre-Post	Pre-control Make
7.	EPA Six Cities Los Angeles	175	A/F DWELL RPM Timing	HC CO NOx	HC CO NOx	NONE	NONE	Pre	65-71 Make Weight Cubic displacement No. cylinders

TRW CAPE-13

TRW's Cape-13 data system provided the basis for empirically defining the loaded mode emission standards. The study performed over the 1971 - 1972 period provides the most comprehensive data base collected to date on California vehicles. It consists of key mode, CVS and engine diagnostic data on approximately 450 uncontrolled, 1966 - 1970 controlled and post-1970 vehicles. The data system also contains information on maintenance effectiveness and associated repair cost for several maintenance treatments. Data collected on engine and emission deterioration is used in determining the effects of changes in emission levels on rejection rates.

ARB SURVEILLANCE

A sample of approximately 2,000 vehicle emission measurements taken during 1971 was selected from the ARB Surveillance Data Base. Idle HC and idle CO measurements represent the primary data available from the surveillance program directly applicable to this study*. The data set also contains basic vehicle characteristic data which was also utilized in the study. This data set was extensively analyzed for potential use in developing the vehicle classification system.

ARB ADVANCED VEHICLES

Emission data on 165 vehicles equipped with catalytic control systems were provided by the ARB. There were three fleets of cars, each with a different control system. HC and CO CVS measurements were available for the first two fleets (65 cars). Only plotted results of averages were available for the last fleet (100 cars). No engine diagnostics were recorded other than the air-fuel ratios.

*The basic equations for converting from 7 mode (Hot) to CVS are given in Appendix B.

NORTHROP/OLSON (ARB)

The Northrop/Olson data set contained emission data on pre-1966 and 1966 - 1970 vehicles. Mass data was measured using 7-mode procedures and the key mode measurements did not include NOx. Pre and post tune data were available. The sample size was 1,500 cars. Engine characteristics were available, but few engine diagnostics were recorded.

AAA

The Automobile Club of Southern California supplied a 1972 documentation of their engineering department's surveillance of (new car) emissions. Due to small sample sets in other years and lack of documentation, only the 1972 results were available. The data consisted of California 7-mode measurements for HC, CO and NOx. Approximately 100 cars were tested. The only engine diagnostics recorded were timing and the fuel-air ratio. Since 7-mode results are not being used in the data base for this study, the AAA measurements have been filed for later reference.

EPA PRE-CONTROLLED

EPA supplied a data base on tape of 100 cars - all pre-control years. Pre and post maintenance data were available. HC and CO readings were available for 7-mode, CVS and the three loaded modes. NOx readings were available from CVS measurements only. The only engine diagnostic recorded was the air-fuel ratio.

EPA SIX CITIES

Emissions data developed by the EPA in their Emission Factor Program measured the emissions of vehicles (1965 - 1971 models) owned and used by the public in six cities, one of which was Los Angeles. The 175 vehicles from the Los Angeles area were used for the data base in this study. Exhaust emissions tests had been performed in accordance with the 1975 Federal Test Procedures. Evaporative emissions utilized the SHED technique. CVS and idle measurements for HC, CO and NOx were available.

3.3 STATISTICAL POOLING AND ANALYSIS

Emissions and diagnostic data from several different studies have been collected and processed for potential application in the analysis (See Table 3-1). While TRW's Cape-13 Data Base contained the information required to define optimal loaded mode standards, it became important to augment this data with additional empirical results. A large, internally consistent, data set is essential in developing the most efficient vehicle classification design because of the potential number of sub-classifications (e.g., the controlled small engine). Pooling efforts to supplement TRW's Data Base were undertaken where consistent information was available.

The attempted pooling of these samples was complicated by the fact that each of the associated studies was carried out under a different set of conditions. While all samples were collected from vehicles operating in the Los Angeles Basin, the potential for basic differences in reported emissions had to be evaluated prior to pooling. These differences could arise as a result of:

1) Test procedures
2) Vehicle sample size and characteristics
3) Test time frame

Initial pooling efforts were focused in two areas:

- Population key mode emissions
- Pre/post maintained CVS mass emissions

Modal data collected from TRW, ARB and Northrop/Olson were examined in detail. In the case of the ARB data only idle emission signatures were available and consequently this date set had only limited utility.

Statistical Emissions of Candidate Studies

Table 3-2 presents a summary of the basic statistical properties of the assembled data. The estimated variance for each of the measurements should be viewed in relative terms, since most vehicle population emissions are log normally distributed. This characteristic is illustrated in Figure 3-2. It should be noted that the derivation of emission standards based on normal distributions can lead to substantial errors.

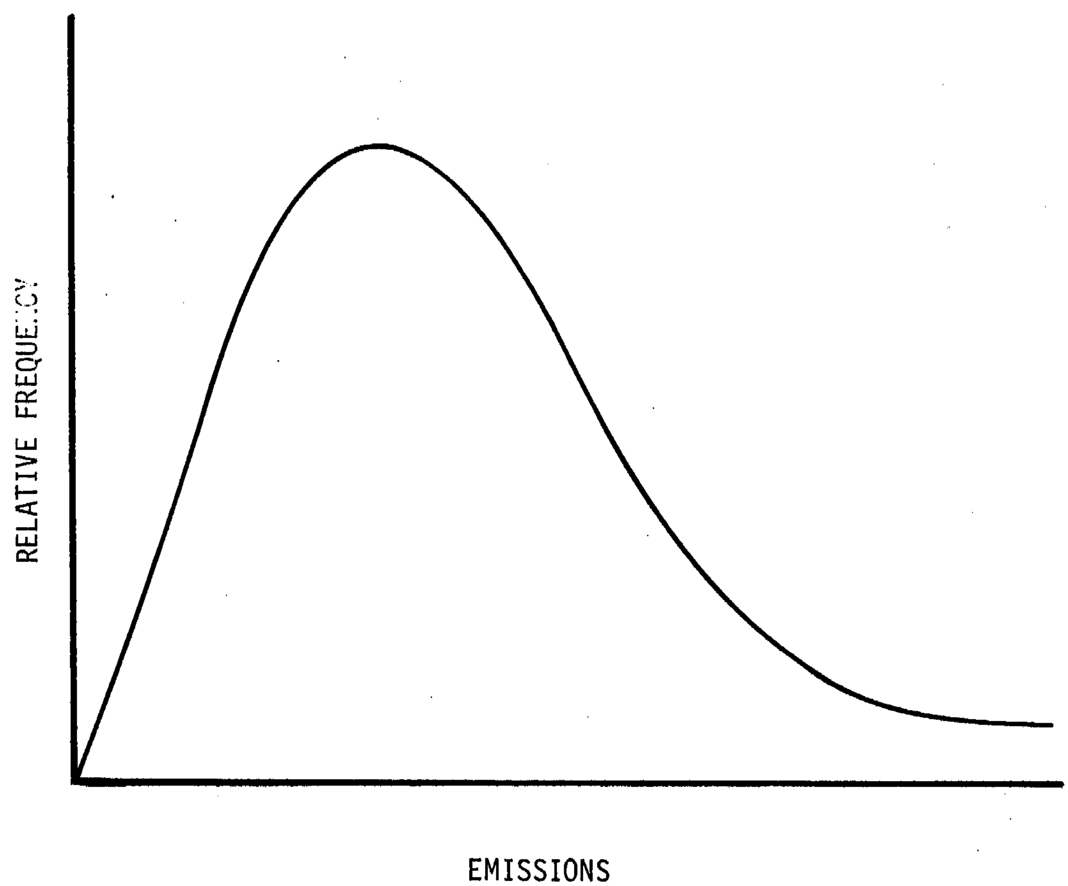

Figure 3-2. A Log Normal Distribution

TABLE 3-2

SUMMARY OF EMISSION CHARACTERISTICS*

KEY MODES

SOURCE *		IDLE MEAN	IDLE SD	LOW CRUISE MEAN	LOW CRUISE SD	HIGH CRUISE MEAN	HIGH CRUISE SD	CVS MEAN	CVS SD
1. CAPE-13, TRW	CO	4.48	3.02	1.88	2.03	1.80	2.08	86.64	49.95
	HC	490.89	711.93	321.85	377.09	246.03	331.08	7.32	5.22
	NOx	83.61	84.40	1344.07	741.82	2202.27	961.42	5.06	2.12
2. ARB SURVEILLANCE	CO	3.11	2.48	----	----	----	----	----	----
	HC	292.28	314.15	----	----	----	----	----	----
	NOx	----	----	----	----	----	----	----	----
3. EPA PRE-CONTROL	CO	5.10	2.54	2.47	1.59	2.00	1.47	129.30	72.45
	HC	676.56	546.23	460.32	435.11	359.59	384.19	12.79	13.48
	NOx	----	----	----	----	----	----	5.27	1.34
4. NORTHROP/ OLSON (ARB)	CO	4.82	3.08	2.15	2.25	1.77	2.08	----	----
	HC	540.25	688.68	324.00	340.16	238.52	438.10	----	----
	NOx	----	----	----	----	----	----	----	----
5. ARB ** ADVANCED VEHICLES	CO	----	----	----	----	----	----	2.92	1.44
	HC	----	----	----	----	----	----	.36	.174
	NOx	----	----	----	----	----	----	2.04	.348
6. EPA SIX-CITIES	CO	----	----	----	----	----	----	74.33	39.99
	HC	----	----	----	----	----	----	7.46	8.02
	NOx	----	----	----	----	----	----	3.79	1.81

* AAA data not presented.

** Data from 65 of the 165 cars available used for these calculations.

The following null and alternate hypotheses were used in assessing the usability of the various data sets*:

H_0: The record samples were drawn from the same population

H_1: The record samples were not drawn from the same population

A definitive test with a 95 percent level of confidence was used to compare the samples with the baseline TRW data for each parameter set (e.g., idle CO). The means and variances were compared by standard analysis of variance procedures for those samples having means that were not statistically different. An F-test was used to compare the variance. Only those samples having statistically similar means and variances were deemed to have been obtained from the same population.

The results from the pooling exercise are summarized below:

- For key mode emissions, only the TRW and Northrop/Olson samples had good statistical agreement. Idle HC and idle CO emissions from the ARB Data Base appeared consistently lower for the same sample period.

- The TRW Data Base provides the only pre/post maintenance CVS mass emission results. A comparison between the EPA Six City study and the TRW data for pre-maintained cars reveal statistically consistent results.

- TRW, Northrop/Olson and EPA engine diagnostic data on pre-maintained vehicles showed a consistent trend.

In summary, the vehicle classification design was developed for combining the TRW and Northrop/Olson loaded mode emission data bases.** Estimates of emission reduction performance in various key mode emission standards were compiled using the TRW Data Base.

*In all cases TRW's Cape-13 data were used as the benchmark

**In cases where the sample size were extensively small, the ARB idle data was used to augment this sample.

Engineering Considerations for Limiting Key Mode Base to TRW/Olson

Higher levels of idle emissions are indicated in the TRW/Olson data than the ARB surveillance data (particular idle CO). It is necessary to evaluate the possible cause of these differences and to assess the potential impact of using either data sets in setting emission standards.

The most probable explanation for having different average idle emissions is that the populations tested by ARB and TRW/Olson were not identical. Lower average emissions would primarily result from evaluating both newer vehicles and vehicles with lower average mileages.* One example that would strongly influence average emission levels is the inclusion of the 1971 fourth quarter data in the ARB data set. These data would include new, 1972 vehicles which had considerably lower idle emissions than previous model year vehicles - 1972 vehicles were certified against more stringent standards and on the new CVS test procedure. This lower idle emission would be found with the class of vehicles including the 1972 model years.

Another possible effect on the test population would be the inclusion of an over representation of "lower than average" emitting classes of vehicles. It is known that there are significant differences in emissions between engine classes and it is possible to have an over representation of "low emitting" classes by either chance or by forced acquisition of specific vehicle classes. Lastly, it should be noted that procedural differences in measurement techniques (e.g., laboratory versus test site) could account for some of the variances between the two data sets.

* For example, for the 1971-1972 period the ARB did not include pre-1966 vehicles in its emissions surveillance program. This would obviously result in a lower level of emissions for the fleet tested vis-a-vis the CAPE-13 program which included this class of vehicle.

A difference in test vehicle populations is strongly suggested by statistical comparison. Also, it is important, in quantifying the baseline vehicle emissions, that time/mileage and population representation factors be accounted for. In this respect the TRW/Olson data were sales weighted in order to elimate test population biases; and these data can additionally be adjusted for time and mileage affects in order to establish updated standards.. SB479 requires that these considerations and the type of emission control systems which are not identified in the ARB data are to be considered in generating standards.

One additional consideration should be noted. The use of data having lower average emissions, if both sets are judged to be equally valid, would be less desirable in this program. Lower emissions would dictate lower standards which could result in rejecting a larger percentage of the vehicle population than originally planned. In this case there would be an increased risk of sending vehicles to maintenance that would not respond or possibly even react negatively to maintenance (errors of commission). This would cause poor program results and increase the incidence of public dissatisfaction with the program.

Modal Emission Distribution

As outlined earlier the distribution of emissions within the vehicle population will have a significant impact on the design of effective emission standards. One way to depict the distribution characteristics of modal emission is through the use of cumulative frequency distributions (CFD).

Figures 3-3 through 3-5 show cumulative population frequency distribution for HC, CO and NOx emission respectively. Panels A, B and C of Figure 3-3 present emission frequency distributors for idle, low cruise and high cruise measurement modes. Similar modal breakouts are also given for CO and NOx (Figures 3-4 and 3-5). Each panel also shows individual age group distributions for the three control classes. This data was obtained from the CAPE-13 experimental program and compares quite **favorably** (idle emissions) with the ARCO test results [1].

Table 3-3 presents technical data on the cycles used in developing the experimental data:

TABLE 3-3

Key Mode Cycles

Vehicle Inertia Weight	Horsepower Setting	Driving Cycles: High Cruise	Low Cruise	Idle
4,000 lbs. & up	30 HP @ 50 MPH	49 MPH	33 MPH	0
3,000-3,500 lbs.	30 HP @ 50 MPH	45 MPH	30 MPH	0
2,000-2,500 lbs.	15 HP @ 50 MPH	37 MPH	23 MPH	0

Notes:

1. 2,000-2,500 lb. vehicles with four speed transmissions are driven in third gear.
2. Automatic transmissions are set in neutral at idle.

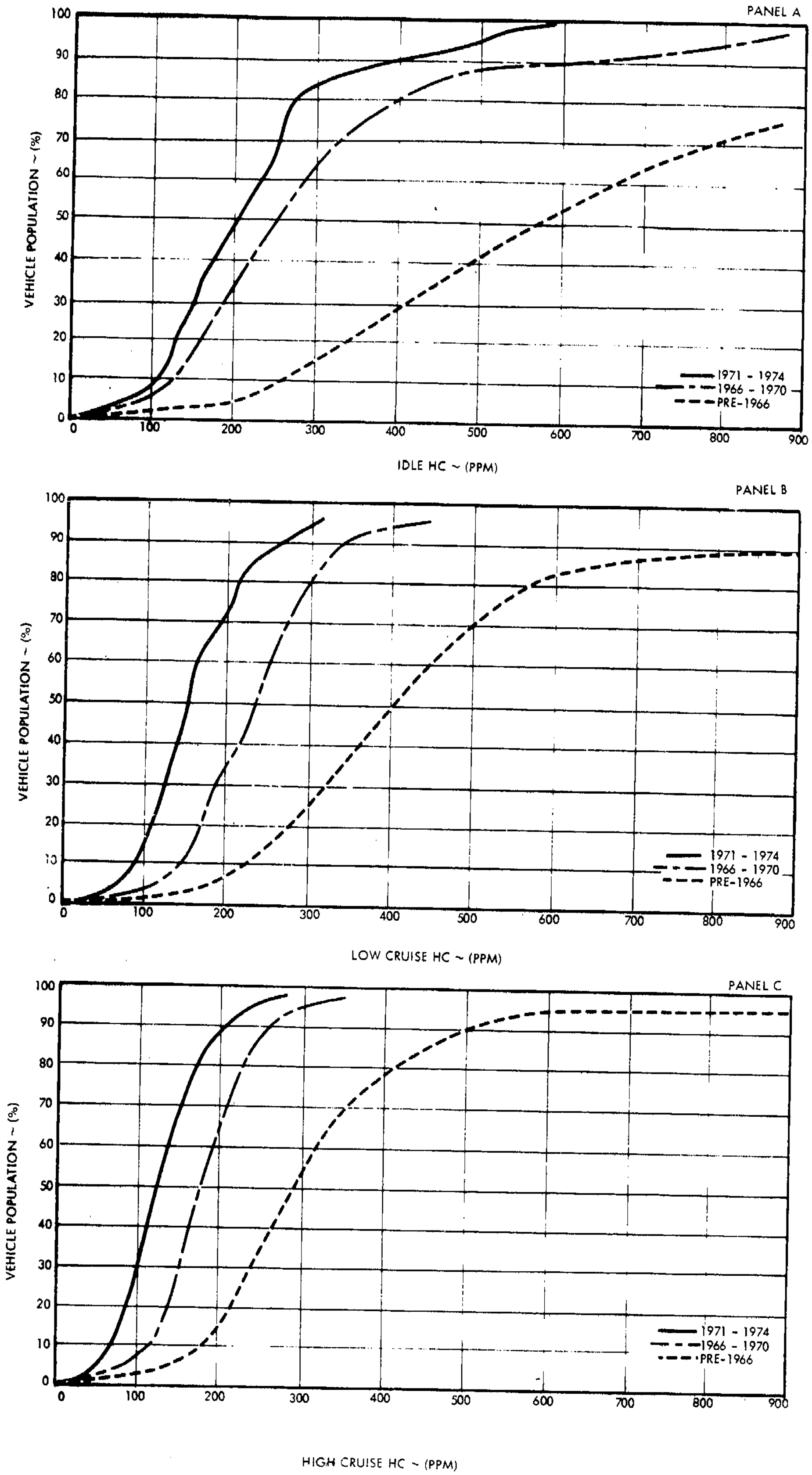

Figure 3-3. Cumulative Frequency Distribution for HC

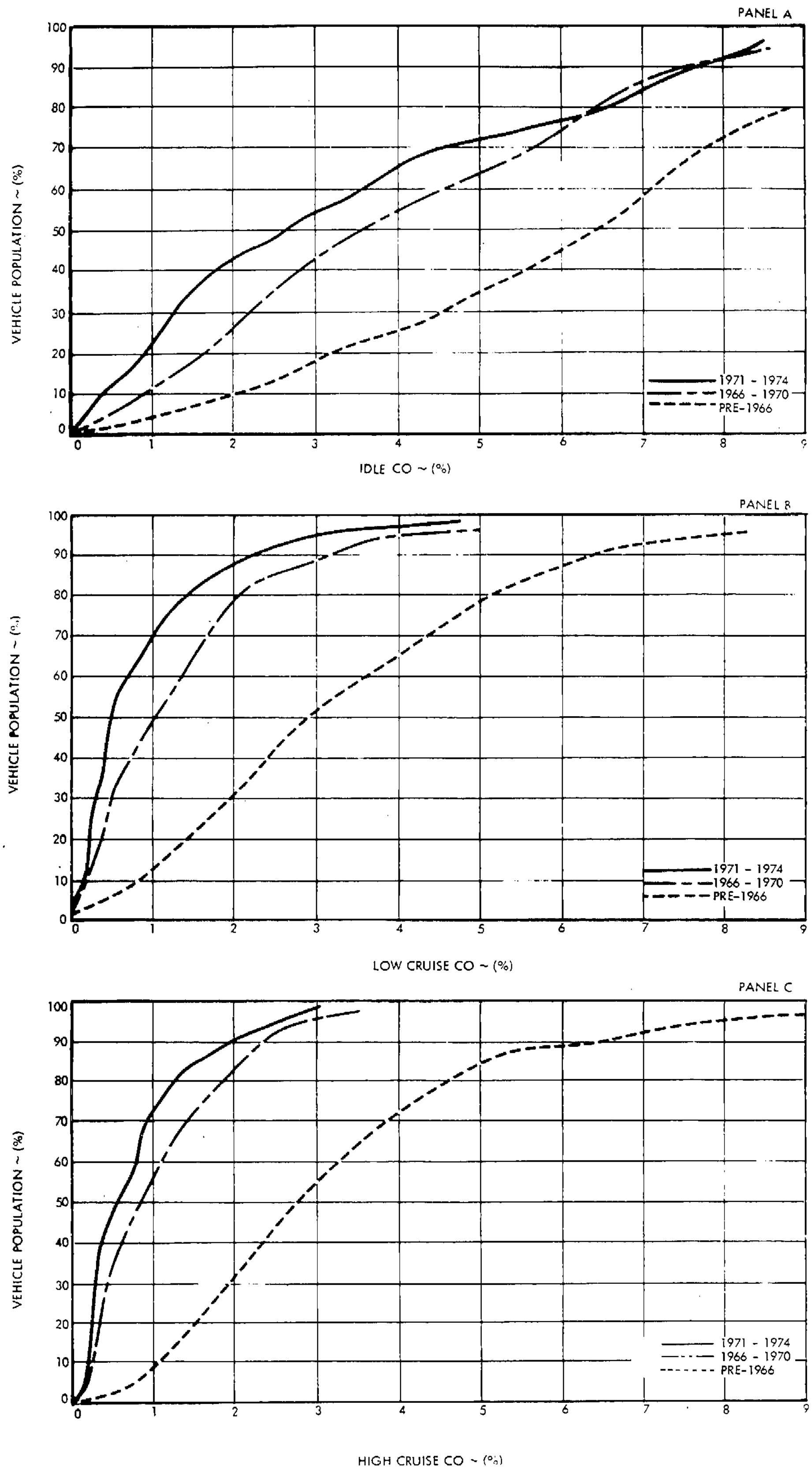

Figure 3-4. Cumulative Frequency Distribution for CO

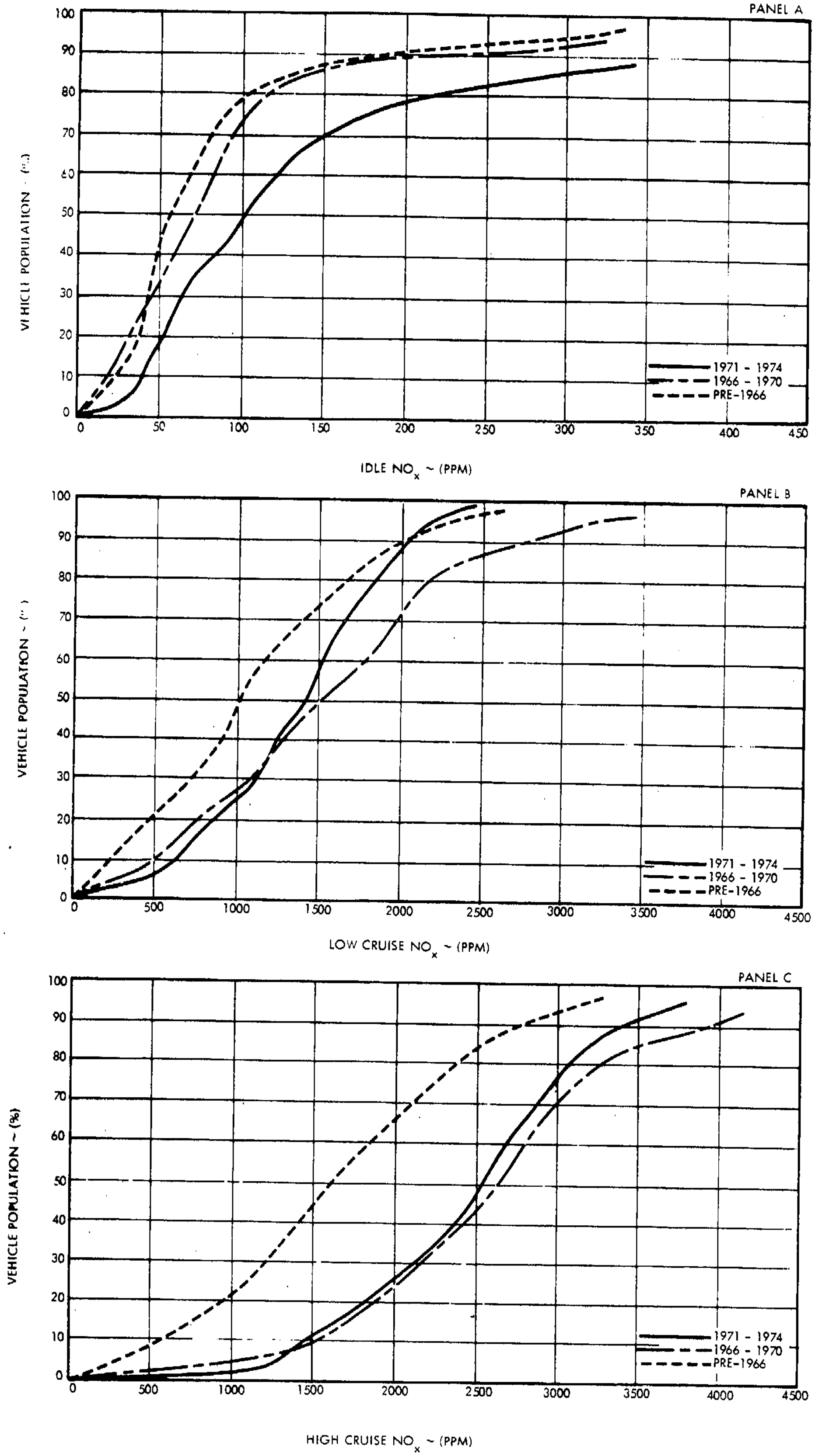

Figure 3-5. Cumulative Frequency Distribution for NOx

3.4 VEHICLE CLASSIFICATION DESIGN

Before vehicular emission standards can be established, the question of population homogeneity must be resolved. If the vehicle population consists of several different emissions groups, because of inherent design characteristics, then a single set of standards would be inappropriate. For example, small displacement four cylinder engines appear to have a significantly higher CO emission concentration at idle than either six or eight cylinder engines. Thus, in a classification design where four's were integrated in with six's and eight's, they would bear a disproportionate amount of the costs. Therefore, it is desirable to develop a classification scheme which takes into account differences in vehicle emission behavior.

Basically, the question of population homogeneity can be broken down into two parts. First, do any significant differences among vehicular emission concentrations exist, and second, if so, where do they lie? A statistical technique known as analysis of variance was used to answer the first part of the question while the second part was answered with a multiple comparison method developed by Scheffé [2]. These procedures are discussed below along with their results. These results are then generalized to develop an acceptable vehicle classification design.

Analysis of Variance Model

A two-way fixed effects analysis of variance model with multiple covariates was used in the development of the vehicle classification scheme. Basically, the model assumes that the key mode emission concentrations can be explained in terms of a linear combination of various design factors, such as weight, displacement, and age, caused effects. Using the appropriate statistical techniques, this model will indicate which factors have a significant influence on emission concentration and, therefore, should be included in the vehicle classification design.

The analysis of variance model used considers two different kinds of effects, fixed and covariate. Fixed effects are design factors which occur at a finite number of discrete levels. For example, the number of cylinders is a fixed effect with three levels. Furthermore, a fixed effect can be dealt with in a controlled experimental manner. A covariate effect, on the other hand, cannot be controlled experimentally and must be "adjusted for" statistically. This is the case when the effect of cylinders on emissions is being investigated. Adjustments for the effect of displacement, weight, etc., must also be taken into account since engines with the same number of cylinders are not all of the same type.

Ideally, all factors of engine and vehicle design which might influence key mode emission concentrations such as carburetion, ignition, and projected frontal area should be analyzed for statistically significant effects. Operationally, however, this was not practicable. Therefore, the investigation was limited to those factors which could be readily assessed at a vehicle inspection station either from the vehicle's registration card or visual appearance. Furthermore, it was recognized that from an engineering stand point, certain types of pollution control equipment would also have to be considered.

Thus on the basis of the above criteria, five design factors were selected for detailed study. They were age, weight, displacement, number of cylinders, and type of control. The last factor was considered only on vehicles between vintages 1966 and 1970, and consisted of classifying the exhaust control device as either air (air pump) or non-air (usually engine modification). Of these five factors adequate data existed to explore their effects on emission concentration for all but weight. Therefore, it was necessary to drop weight from the final set of design factors under consideration.

The four candidate design factors were used in two types of analysis of variance. The first type explored the effects of control devices on emission concentrations of vintage 1966-1970 vehicles. In this analysis, control type and cylinder number were the fixed effects and displacement the covariate effect. The second analysis of variance was designed to assess the significance of all four factors interacting together. Age and cylinder number appeared as fixed effects and displacement and control type as covariate effects. The actual analysis of variance models are discussed in more detail below.

The control by cylinders analysis of variance model used was:

$$\log_e Y_{ijk} = m + c_i + n_j + cn_{ij} + \alpha . d_{ijk} + e_{ijk}$$

where:

Y_{ijk} is the emission concentration for the i th control level, j th cylinder level and k th replicate

m is the mean effect

c_i is the control effect - $i = \begin{cases} 1 & \text{(AIR)} \\ 2 & \text{(NON-AIR)} \end{cases}$

n_j is the cylinders effect - $j = \begin{cases} 1 & (4) \\ 2 & (6) \\ 3 & (8) \end{cases}$

cn_{ij} is the control x cylinder - $i = \begin{Bmatrix} 1 \\ 2 \end{Bmatrix}$, $j = \begin{Bmatrix} 1 \\ 2 \\ 3 \end{Bmatrix}$

d_{ijk} is the engine displacement (in cubic inches) associated with ith control level, jth cylinder level and kth replicate

α is the covariate coefficient.

e_{ijk} is the random sampling error associated with the ith control level, jth cylinder level, and kth replicate.

The logarithm of the emission concentration has been used in the model in order to adjust for the fact that the concentrations are log-normally distributed. The mean effect indicates that all the vehicles have some inherent emission level while the interactions term cn_j allows for the possibility that a particular combination of cylinders and control may interact in some way to produce an additional effect.

The model configuration for the age by cylinders analysis of variance was:

$$\log_e Y_{ijk} = m + v_i + n_j + vn_{ij} + \alpha d_{ijk} + \beta a_{ijk} + \gamma na_{ijk} + e_{ijk}$$

where:

Y_{ijk} is the emission concentration for the ith vintage level, Jth cylinder level, and kth replicate

m is the means effect

v_i is the vehicle vintage (age) effect - $i = \begin{matrix}1\\2\\3\end{matrix}\left\{\begin{matrix}(LT66)\\(66\text{-}70)\\(71\text{-}74)\end{matrix}\right.$

n_j is the cylinders effect - $j = \begin{matrix}1\\2\\3\end{matrix}\left\{\begin{matrix}(4)\\(6)\\(8)\end{matrix}\right.$

vn_{ij} is the vintage x cylinders interaction effects - $i = \left\{\begin{matrix}1\\2\\3\end{matrix}\right\}$, $j = \left\{\begin{matrix}1\\2\\3\end{matrix}\right\}$

d_{ijk} is the engine displacement (in cubic inches) associated with the ith vintage level, jth cylinder level, and kth replicate

a_{ijk} is a zero-one variable indicating whether the vehicle associated with the ith vintage level, jth cylinder level, and kth replicate has an air pump (1 - yes, 0 - no)

na_{ijk} is a zero-one variable indicating whether the vehicle associated with the ith vintage level, jth cylinder level, and kth replicate has a non-air pump type control device (1 - yes, 0 - no)

α, β, γ are the covariate coefficients

e_{ijk} is the random sampling error associated with the ith vintage level, jth cylinder level and kth replicate.

The three different age or vintage groups, pre-1966, 1966 - 1970 and 1971 - 1974, considered in this model were established so that vehicles in the same group faced similar legislated emission standards. It was not possible to consider all years reported because of limitations in the data. In addition, only the middle age group of cars was classified by control type since pre-1966 vehicles had no such controls and the post-1970 vehicles used a different kind of control concept which was fairly uniform in its application.

Both analyses of variance were performed using the UCLA General Linear Hypothesis Biomedical Computer Program (BMD05V). In general, this program uses linear regression techniques to estimate the effects of the various design factors contained in the model. It then computes F-statistics for each of the effects which can be used to determine whether they are statistically significant from zero. The data for the samples came from the TRW/Olson test results. However, a separate control by cylinders analysis of variance was performed using the ARB data base in order to compare the results. This indirect procedure was adopted since statistical tests indicated that the ARB and TRW/Olson emission data were not directly comparable (see Section 3.3).

After the analyses of variance were performed, the Scheffé multiple comparison procedure was used to determine which control-cylinder group were statistically different. This was done by analyzing the difference between pairs of means to see whether they were significant. By doing so it was possible to develop homogeneous cylinder subsets -- subsets of cylinder means, no pair of which are statistically different. Homogeneous age and cylinder subsets were also developed for the age by cylinders analysis of variance. In this way it was possible to determine not only which design factors significantly influence emission concentrations but also at what levels the effect exists.

Finally, a set of stepwise linear regression equations was developed in order to explore the relationships among weight, displacement, and cylinder number. Each design factor was expressed as a function of the other two, and the stepwise technique was employed to identify that variable which gave the greatest decrease in the error sum of squares. Thus, in the event it became operationally desirable to use weight as a classification factor, it would be possible to predict weight on the basis of a vehicle's displacement and cylinder number.

<u>Analysis of Variance and Stepwise Linear Regression Results</u>

The analysis of variance and stepwise linear regression results are presented in the tables which follow. They are divided into five groups: the control by cylinders analysis of variance, the age by cylinders analysis of variance, the control by cylinders multiple comparisons, the age by cylinders multiple comparisons, and the stepwise linear regressions. Each group will be discussed below.

The control by cylinders analysis of variance results are shown in Tables 3-4 through 3-11. The analysis was performed for two different emission species, HC and CO, and three key modes, idle, low cruise and high cruise. NOx emissions were not included because of insufficient data. In addition, the analysis of variance was repeated for idle HC and idle CO using the ARB test results collected during the year 1971 (the same year as the TRW test results).

Each of the control by cylinders analysis of variance tables presents (as do the age by cylinder analysis of variance tables) the following information:

1) Cell means, $\overline{X}$, unadjusted for log-normal distribution.
2) Cell means, $\overline{X}_{ln}$, adjustment for log-normality
3) Cell standard deviations, S_{ln}, adjusted for log-normal distribution
4) Cell sample size, n.

Besides the above information, the tables also show the value of the F-statistic for each effect under consideration along the two sets of critical F values. These critical values indicate whether or not the corresponding effect is significant at the 0.05 (shown in parenthesis) and 0.01 levels. In order for an effect to be significant at a particular level, its F score must be equal to or greater than the initial value. The significance levels, themselves, indicate the likelihood of classifying an effect as significant when, in reality, it is not. For the 0.05 and 0.01 levels, this corresponds to five times out of one hundred and one time out of one hundred, respectively.

Tables 3-12 through 3-17 gives the results of the age by cylinders analysis of variance. This analysis was performed only with the TRW/Olson data since the ARB 1971 sample did not contain an adequate number of pre 1966 vehicles. Tha tables are similar in content to the control by cylinders tables discussed above. It should be noted, however, that the control covariate applies only to the 1966 through 1970 age group.

The multiple comparision results for both analyses of variance are presented in Tables 3-18 through 3-20. Table 3-18 shows which cylinder groups are not significantly different at the 0.05 level for air and non-air equipped vehicles. The TRW/Olson and ARB figures are combined into one table for easy comparison. In Table 3-19, the homogeneous age subsets (subsets of emission concentration by age which do not differ significantly) are given for the age by cylinders - analysis of variance. Table 3-20 displays (total of the homogeneous cylinder subsets for the population) age by cylinders (total population) analysis of variance.

Finally, Tables 3-21 through 3-23 list the results of the stepwise linear regressions. Each step introduces that variable or constant which caused the greatest decrease in the error sum of squares. Also reported are the T-scores, which indicate the significance of the coefficient or constant, the coefficient of multiple determination, which tells what fraction of the total variation in the dependent variable is explained by the regression equation, and the standard error of the estimate.

TABLE 3-4

CONTROL BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR IDLE - HC

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
AIR	$\overline{X} = 117.5$ $\overline{X}_{ln} = 4.533$ $S_{ln} = 0.6168$ $n = 32$	$\overline{X} = 314.2$ $\overline{X}_{ln} = 4.881$ $S_{ln} = 1.236$ $n = 16$	$\overline{X} = 259.9$ $\overline{X}_{ln} = 5.098$ $S_{ln} = 0.8215$ $n = 118$
NONAIR	$\overline{X} = 319.1$ $\overline{X}_{ln} = 5.480$ $S_{ln} = 0.6978$ $n = 36$	$\overline{X} = 374.1$ $\overline{X}_{ln} = 5.479$ $S_{ln} = 0.7147$ $n = 33$	$\overline{X} = 278.0$ $\overline{X}_{ln} = 5.397$ $S_{ln} = 0.6133$ $n = 245$

EFFECT	CRITICAL F VALUE *	F VALUE
CONTROL	(3.86) 6.70	44.33
CYLINDERS	(3.02) 4.66	11.62
CONTROL x CYLINDERS INTERACTION	(3.02) 4.66	4.84
DISPLACEMENT COVARIATE	(3.86) 6.70	16.85

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-5

CONTROL BY CYLINDERS ANALYSIS OF VARIANCE REPORTS FOR LOW CRUISE - HC

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
AIR	$\overline{X}$ = 367.6 $\overline{X}_{1n}$ = 5.033 S_{1n} = 0.9894 n = 16	$\overline{X}$ = 145.5 $\overline{X}_{1n}$ = 4.727 S_{1n} = 0.8190 n = 5	$\overline{X}$ = 193.2 $\overline{X}_{1n}$ = 5.042 S_{1n} = 0.6319 n = 65
NONAIR	$\overline{X}$ = 214.2 $\overline{X}_{1n}$ = 5.250 S_{1n} = 0.5295 n = 16	$\overline{X}$ = 357.7 $\overline{X}_{1n}$ = 5.341 S_{1n} = 0.7745 n = 19	$\overline{X}$ = 256.5 $\overline{X}_{1n}$ = 5.324 S_{1n} = 0.5282 n = 145

EFFECT	CRITICAL F VALUE *	F VALUE
CONTROL	(3.89) 6.76	7.93
CYLINDERS	(3.04) 4.71	4.77
CONTROL x CYLINDERS INTERACTION	(3.04) 4.71	0.55
DISPLACEMENT COVARIATE	(3.89) 6.76	9.43

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-6

CONTROL BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR HIGH CRUISE - HC

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
AIR	$\overline{X}$ = 132.7 $\overline{X}_{1n}$ = 4.672 S_{1n} = 0.6057 n = 16	$\overline{X}$ = 124.3 $\overline{X}_{1n}$ = 4.529 S_{1n} = 1.020 n = 5	$\overline{X}$ = 155.1 $\overline{X}_{1n}$ = 4.839 S_{1n} = 0.5994 n = 65
NONAIR	$\overline{X}$ = 152.1 $\overline{X}_{1n}$ = 4.968 S_{1n} = 0.5718 n = 16	$\overline{X}$ = 303.8 $\overline{X}_{1n}$ = 4.968 S_{1n} = 0.8954 n = 19	$\overline{X}$ = 209.5 $\overline{X}_{1n}$ = 5.066 S_{1n} = 0.5688 n = 145

EFFECT	CRITICAL F VALUE *	F VALUE
CONTROL	(3.89) 6.76	4.84
CYLINDERS	(3.04) 4.71	6.17
CONTROL x CYLINDERS INTERACTION	(3.04) 4.71	0.18
DISPLACEMENT COVARIATE	(3.89) 6.76	8.89

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-7

CONTROL BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR IDLE - CO

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
AIR	$\overline{X} = 1.93$ $\overline{X}_{ln} = 0.395$ $S_{ln} = 0.742$ $n = 32$	$\overline{X} = 2.08$ $\overline{X}_{ln} = 0.301$ $S_{ln} = 0.958$ $n = 16$	$\overline{X} = 2.94$ $\overline{X}_{ln} = 0.834$ $S_{ln} = 0.764$ $n = 118$
NONAIR	$\overline{X} = 4.34$ $\overline{X}_{ln} = 1.27$ $S_{ln} = 0.684$ $n = 36$	$\overline{X} = 4.42$ $\overline{X}_{ln} = 1.12$ $S_{ln} = 1.05$ $n = 33$	$\overline{X} = 4.06$ $\overline{X}_{ln} = 1.03$ $S_{ln} = 1.08$ $n = 245$

EFFECT	CRITICAL F VALUE *	F VALUE
CONTROL	(3.86) 6.70	24.17
CYLINDERS	(3.02) 4.66	1.91
CONTROL x CYLINDERS INTERACTION	(3.02) 4.66	4.36
DISPLACEMENT COVARIATE	(3.86) 6.70	1.62

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-8

CONTROL BY CYLINDERS ANALYSIS FOR VARIANCE RESULTS FOR LOW CRUISE - CO

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
AIR	$\overline{X} = 1.29$ $\overline{X}_{ln} = -0.0986$ $S_{ln} = 1.01$ $n = 16$	$\overline{X} = 1.49$ $\overline{X}_{ln} = 0.309$ $S_{ln} = 0.470$ $n = 5$	$\overline{X} = 1.01$ $\overline{X}_{ln} = -0.300$ $S_{ln} = 0.889$ $n = 65$
NONAIR	$\overline{X} = 2.13$ $\overline{X}_{ln} = 0.367$ $S_{ln} = 0.924$ $n = 16$	$\overline{X} = 1.61$ $\overline{X}_{ln} = -0.310$ $S_{ln} = 1.32$ $n = 19$	$\overline{X} = 1.00$ $\overline{X}_{ln} = -0.532$ $S_{ln} = 1.07$ $n = 145$

EFFECT	CRITICAL F VALUE *	F VALUE
CONTROL	(3.89) 6.76	0.31
CYLINDERS	(3.04) 4.71	3.01
CONTROL x CYLINDERS INTERACTION	(3.04) 4.71	2.07
DISPLACEMENT COVARIATE	(3.89) 6.76	1.32

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-9

CONTROL BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR HIGH CRUISE - CO

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
AIR	$\overline{X} = 0.485$ $\overline{X}_{1n} = -1.66$ $S_{1n} = 1.33$ $n = 16$	$\overline{X} = 1.37$ $\overline{X}_{1n} = -0.0316$ $S_{1n} = 0.926$ $n = 5$	$\overline{X} = 1.02$ $\overline{X}_{1n} = -0.374$ $S_{1n} = 0.981$ $n = 65$
NON AIR	$\overline{X} = 1.29$ $\overline{X}_{1n} = -0.0915$ $S_{1n} = 1.00$ $n = 16$	$\overline{X} = 1.39$ $\overline{X}_{1n} = -0.210$ $S_{1n} = 1.07$ $n = 18$	$\overline{X} = 0.784$ $\overline{X}_{1n} = -0.706$ $S_{1n} = 0.990$ $n = 144$

EFFECT	CRITICAL F VALUE *	F VALUE
CONTROL	(3.89) 6.76	2.72
CYLINDERS	(3.04) 4.71	2.40
CONTROL x CYLINDERS INTERACTION	(3.04) 4.71	11.88
DISPLACEMENT COVARIATE	(3.89) 6.76	0.03

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-10

ARB_{71} CONTROL BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR IDLE - HC

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
AIR	$\overline{X} = 194.8$ $\overline{X}_{ln} = 5.038$ $S_{ln} = 0.5970$ $n = 134$	$\overline{X} = 211.4$ $\overline{X}_{ln} = 5.105$ $S_{ln} = 0.6856$ $n = 69$	$\overline{X} = 293.2$ $\overline{X}_{ln} = 5.414$ $S_{ln} = 0.6372$ $n = 460$
NONAIR	$\overline{X} = 386.8$ $\overline{X}_{ln} = 5.657$ $S_{ln} = 0.6999$ $n = 303$	$\overline{X} = 305.3$ $\overline{X}_{ln} = 5.569$ $S_{ln} = 0.5369$ $n = 225$	$\overline{X} = 325.5$ $\overline{X}_{ln} = 5.643$ $S_{ln} = 0.5453$ $n = 625$

EFFECT	CRITICAL F VALUE *	F VALUE
CONTROL	(3.84) 6.64	147.47
CYLINDERS	(2.99) 4.60	34.59
CONTROL x CYLINDERS INTERACTION	(2.99) 4.60	13.88
DISPACEMENT COVARIATE	(3.84) 6.64	40.43

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-11

ARB_{71} CONTROL BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR IDLE - CO

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
AIR	$\overline{X} = 1.99$ $\overline{X}_{1n} = 0.408$ $S_{1n} = 0.803$ $n = 134$	$\overline{X} = 1.76$ $\overline{X}_{1n} = 0.0210$ $S_{1n} = 1.18$ $n = 69$	$\overline{X} = 2.90$ $\overline{X}_{1n} = 0.809$ $S_{1n} = 0.823$ $n = 460$
NONAIR	$\overline{X} = 3.56$ $\overline{X}_{1n} = 0.938$ $S_{1n} = 0.875$ $n = 303$	$\overline{X} = 3.77$ $\overline{X}_{1n} = 0.875$ $S_{1n} = 1.20$ $n = 225$	$\overline{X} = 3.87$ $\overline{X}_{1n} = 0.995$ $S_{1n} = 1.07$ $n = 625$

EFFECT	CRITICAL F VALUE *	F VALUE
CONTROL	(3.84) 6.64	73.15
CYLINDERS	(2.99) 4.60	12.02
CONTROL x CYLINDERS INTERACTION	(2.99) 4.60	11.59
DISPLACEMENT COVARIATE	(3.84) 6.64	0.11

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-12

AGE BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR IDLE - HC

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
LT 66	$\overline{X}$ = 1527. $\overline{X}_{ln}$ = 6.833 S_{ln} = 1.095 n = 43	$\overline{X}$ = 724.2 $\overline{X}_{ln}$ = 6.269 S_{ln} = 0.8652 n = 138	$\overline{X}$ = 730.1 $\overline{X}_{ln}$ = 6.305 S_{ln} = 0.7054 n = 383
66-70	$\overline{X}$ = 224.2 $\overline{X}_{ln}$ = 5.035 S_{ln} = 0.9107 n = 68	$\overline{X}$ = 354.5 $\overline{X}_{ln}$ = 5.284 S_{ln} = 0.9477 n = 49	$\overline{X}$ = 272.1 $\overline{X}_{ln}$ = 5.300 S_{ln} = 0.7009 n = 363
GT 70	$\overline{X}$ = 312.9 $\overline{X}_{ln}$ = 5.624 S_{ln} = 0.5218 n = 27	$\overline{X}$ = 269.5 $\overline{X}_{ln}$ = 5.574 S_{ln} = 0.2268 n = 10	$\overline{X}$ = 217.8 $\overline{X}_{ln}$ = 5.225 S_{ln} = 0.4973 n = 111

EFFECT	CRITICAL F VALUE*	F VALUE
AGE	(3.00) 4.62	87.83
CYLINDERS	(3.00) 4.62	6.79
AGE x CYLINDERS INTERACTION	(2.38) 3.34	7.93
DISPLACEMENT COVARIATES	(3.35) 6.66	38.91
CONTROL COVARIATES	(385) 6.66	47.33

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-13

AGE BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR LOW CRUISE - HC

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
LT 66	$\overline{X}$ = 571.5 $\overline{X}_{ln}$ = 6.143 S_{ln} = 0.6230 n = 19	$\overline{X}$ = 443.1 $\overline{X}_{ln}$ = 5.833 S_{ln} = 0.6347 n = 72	$\overline{X}$ = 453.7 $\overline{X}_{ln}$ = 5.860 S_{ln} = 0.6107 n = 214
66 - 70	$\overline{X}$ = 290.9 $\overline{X}_{ln}$ = 5.142 S_{ln} = 0.7883 n = 32	$\overline{X}$ = 313.5 $\overline{X}_{ln}$ = 5.213 S_{ln} = 0.8200 n = 24	$\overline{X}$ = 236.9 $\overline{X}_{ln}$ = 5.237 S_{ln} = 0.5758 n = 210
GT 70	$\overline{X}$ = 224.3 $\overline{X}_{ln}$ = 5.341 S_{ln} = 0.4066 n = 29	$\overline{X}$ = 222.8 $\overline{X}_{ln}$ = 5.343 S_{ln} = 0.3682 n = 10	$\overline{X}$ = 146.9 $\overline{X}_{ln}$ = 4.920 S_{ln} = 0.3845 n = 111

EFFECT	CRITICAL F VALUE*	F VALUE
AGE	(3.01) 4.64	58.52
CYLINDERS	(3.01) 4.64	5.34
AGE x CYLINDERS INTERACTION	(2.38) 3.33	3.12
DISPLACEMENT COVARIATES	(3.85) 6.68	31.00
CONTROL COVARIATES	(3.85) 6.68	17.18

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-14

AGE BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR HIGH CRUISE - HC

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
LT 66	$\overline{X}$ = 452.5 $\overline{X}_{ln}$ = 5.640 S_{ln} = 0.9255 n = 19	$\overline{X}$ = 339.4 $\overline{X}_{ln}$ = 5.503 S_{ln} = 0.6853 n = 72	$\overline{X}$ = 330.1 $\overline{X}_{ln}$ = 5.559 S_{ln} = 0.5616 n = 214
66 - 70	$\overline{X}$ = 142.4 $\overline{X}_{ln}$ = 4.777 S_{ln} = 0.5892 n = 32	$\overline{X}$ = 266.4 $\overline{X}_{ln}$ = 4.876 S_{ln} = 0.9173 n = 24	$\overline{X}$ = 192.7 $\overline{X}_{ln}$ = 4.996 S_{ln} = 0.5865 n = 210
GT 70	$\overline{X}$ = 166.2 $\overline{X}_{ln}$ = 5.055 S_{ln} = 0.3601 n = 29	$\overline{X}$ = 176.8 $\overline{X}_{ln}$ = 5.123 S_{ln} = 0.3321 n = 10	$\overline{X}$ = 123.3 $\overline{X}_{ln}$ = 4.738 S_{ln} = 0.3952 n = 111

EFFECT	CRITICAL F VALUE *	F VALUE
AGE	(3.01) 4.64	35.28
CYLINDERS	(3.01) 4.64	10.07
AGE x CYLINDERS INTERACTION	(2.38) 3.33	3.34
DISPLACEMENT COVARIATES	(3.85) 6.68	33.57
CONTROL COVARIATES	(3.85) 6.68	11.54

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-15

AGE BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR IDLE - CO

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
LT 66	$\overline{X} = 6.19$ $\overline{X}_{ln} = 1.62$ $S_{ln} = 0.791$ $n = 43$	$\overline{X} = 5.62$ $\overline{X}_{ln} = 1.46$ $S_{ln} = 0.930$ $n = 138$	$\overline{X} = 5.94$ $\overline{X}_{ln} = 1.53$ $S_{ln} = 0.902$ $n = 384$
66 - 70	$\overline{X} = 3.21$ $\overline{X}_{ln} = 0.861$ $S_{ln} = 0.833$ $n = 68$	$\overline{X} = 3.65$ $\overline{X}_{ln} = 0.850$ $S_{ln} = 1.08$ $n = 49$	$\overline{X} = 3.70$ $\overline{X}_{ln} = 0.969$ $S_{ln} = 0.993$ $n = 363$
GT 70	$\overline{X} = 5.17$ $\overline{X}_{ln} = 1.41$ $S_{ln} = 0.843$ $n = 29$	$\overline{X} = 5.00$ $\overline{X}_{ln} = 1.47$ $S_{ln} = 0.575$ $n = 10$	$\overline{X} = 2.72$ $\overline{X}_{ln} = 0.480$ $S_{ln} = 1.15$ $n = 111$

EFFECT	CRITICAL F VALUE *	F VALUE
AGE	(3.00) 4.62	9.05
CYLINDERS	(3.00) 4.62	6.76
AGE x CYLINDERS INTERACTION	(2.38) 3.34	6.51
DISPLACEMENT COVARIATE	(3.85) 6.66	1.01
CONTROL COVARIATE	(3.85) 6.66	16.70

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-16

AGE BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR LOW CRUISE - CO

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
LT 66	$\overline{X} = 4.46$ $\overline{X}_{ln} = 1.35$ $S_{ln} = 0.577$ $n = 19$	$\overline{X} = 3.39$ $\overline{X}_{ln} = 0.822$ $S_{ln} = 1.01$ $n = 72$	$\overline{X} = 2.98$ $\overline{X}_{ln} = 0.750$ $S_{ln} = 1.01$ $n = 214$
66 - 70	$\overline{X} = 1.71$ $\overline{X}_{ln} = 0.134$ $S_{ln} = 0.989$ $n = 32$	$\overline{X} = 1.58$ $\overline{X}_{ln} = -0.181$ $S_{ln} = 1.21$ $n = 24$	$\overline{X} = 1.00$ $\overline{X}_{ln} = -0.460$ $S_{ln} = 1.02$ $n = 210$
GT 70	$\overline{X} = 1.50$ $\overline{X}_{ln} = 0.0529$ $S_{ln} = 0.995$ $n = 29$	$\overline{X} = 1.73$ $\overline{X}_{ln} = 0.0814$ $S_{ln} = 1.14$ $n = 10$	$\overline{X} = 0.631$ $\overline{X}_{ln} = -0.866$ $S_{ln} = 0.858$ $n = 111$

EFFECT	CRITICAL F VALUE *	F VALUE
AGE	(3.01) 4.64	64.75
CYLINDERS	(3.01) 4.64	3.77
AGE x CYLINDERS INTERACTION	(2.38) 3.33	2.00
DISPLACEMENT COVARIATE	(3.35) 6.68	0.13
CONTROL COVARIATE	(3.35) 6.68	1.55

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-17

AGE BY CYLINDERS ANALYSIS OF VARIANCE RESULTS FOR HIGH CRUISE - CO

	4 CYLINDERS	6 CYLINDERS	8 CYLINDERS
LT 66	$\overline{X} = 2.31$ $\overline{X}_{ln} = 0.494$ $S_{ln} = 0.806$ $n = 17$	$\overline{X} = 3.77$ $\overline{X}_{ln} = 0.901$ $S_{ln} = 1.07$ $n = 72$	$\overline{X} = 2.75$ $\overline{X}_{ln} = 0.678$ $S_{ln} = 0.881$ $n = 214$
66 - 70	$\overline{X} = 0.886$ $\overline{X}_{ln} = -0.878$ $S_{ln} = 1.41$ $n = 32$	$\overline{X} = 1.39$ $\overline{X}_{ln} = -0.172$ $S_{ln} = 1.02$ $n = 23$	$\overline{X} = 0.858$ $\overline{X}_{ln} = -0.603$ $S_{ln} = 0.9997$ $n = 209$
GT 70	$\overline{X} = 1.35$ $\overline{X}_{ln} = -0.441$ $S_{ln} = 1.23$ $n = 29$	$\overline{X} = 1.15$ $\overline{X}_{ln} = -0.326$ $S_{ln} = 1.17$ $n = 10$	$\overline{X} = 0.722$ $\overline{X}_{ln} = -0.700$ $S_{ln} = 0.844$ $n = 111$

EFFECT	CRITICAL F VALUE *	F VALUE
AGE	(3.01) 4.64	56.95
CYLINDERS	(3.01) 4.64	3.80
AGE x CYLINDERS INTERACTION	(2.38) 3.33	1.24
DISPLACEMENT COVARIATE	(3.85) 6.68	1.31
CONTROL COVARIATE	(3.85) 6.68	0.13

*Critical Values are for 0.05 ( ) and 0.01 Levels of Significance

TABLE 3-18

HOMOGENEOUS CYLINDER SUBSETS FOR CONTROL VEHICLES

CONTROL	KEY MODE	HOMOGENEOUS * CYLINDER SUBSETS
AIR	IDLE HC	(4, 6), (6, 8)
	IDLE HC ARB	(4, 6), (8)
	IDLE CO	(4, 6, 8)
	IDLE CO ARB	(4), (6), (8)
	LOW CRUISE HC	(4, 6, 8)
	LOW CRUISE CO	(4, 6, 8)
	HIGH CRUISE HC	(4, 6, 8)
	HIGH CRUISE CO	(4, 6, 8)
NON-AIR	IDLE HC	(4, 6, 8)
	IDLE HC ARB	(4, 6, 8)
	IDLE CO	(4, 6, 8)
	IDLE CO ARB	(4, 6, 8)
	LOW CRUISE HC	(4, 6, 8)
	LOW CRUISE CO	(4, 6, 8)
	HIGH CRUISE HC	(4, 6, 8)
	HIGH CRUISE CO	(4, 6, 8)

* Subsets of cylinder means which do not differ significantly at the 0.05 level.

TABLE 3-19

HOMOGENEOUS AGE SUBSETS FOR TOTAL POPULATION

Cylinders	Key Mode	Homogeneous * Age Subsets
4	Idle HC	(LT66),(66-70),(GT70)
	Idle CO	(LT66,GT70), (66-70)
	Low Cruise HC	(LT66),(66-70, GT70)
	Low Cruise CO	(LT66),(66-70, GT70)
	High Cruise HC	(LT66),(66-70),(GT70)
	High Cruise CO	(LT66),(66-70),(GT70
6	Idle HC	(LT66),(66-70, GT70)
	Idle CO	(LT66, GT70),(66-70)
	Low Cruise HC	(LT66),(66-70, GT70)
	Low Cruise CO	(LT66),(66-70, GT70)
	High Cruise HC	(LT66),(66-70, GT70)
	High Cruise CO	(LT66),(66-70, GT70)
8	Idle HC	(LT66), (66-70, GT70)
	Idle CO	(LT66),(66-70),(GT70)
	Low Cruise HC	(LT66),(66-70),(GT70)
	Low Cruise CO	(LT66),(66-70),(GT70)
	High Cruise HC	(LT66),(66-70),(GT70)
	High Cruise CO	(LT66),(66-70, GT70)

* Subsets of age means which do not differ significantly at the 0.05 level.

TABLE 3-20

HOMOGENEOUS CYLINDER SETS FOR TOTAL POPULATION

AGE	KEY MODE	HOMOGENEOUS* CYLINDER SUBSETS
LT 66	IDLE HC	(4), (6, 8)
	IDLE CO	(4, 6, 8)
	LOW CRUISE HC	(4), (6, 8)
	LOW CRUISE CO	(4), (6, 8)
	HIGH CRUISE HC	(4, 6, 8)
	HIGH CRUISE CO	(4, 6, 8)
66 - 70	IDLE HC	(4), (6, 8)
	IDLE CO	(4, 6, 8)
	LOW CRUISE HC	(4, 6, 8)
	LOW CRUISE CO	(4, 6), (6, 8)
	HIGH CRUISE HC	(4, 6), (6, 8)
	HIGH CRUISE CO	(4, 8),(6)
GT 70	IDLE HC	(4, 6), (6, 8)
	IDLE CO	(4, 6, 8)
	LOW CRUISE HC	(4, 6), (8)
	LOW CRUISE CO	(4, 6), (8)
	HIGH CRUISE HC	(4, 6), (8)
	HIGH CRUISE CO	(4, 6, 8)

*Subsets of Cylinder Means Which do not Differ Significantly at the 0.01 Level.

TABLE 3-21

STEPWISE LINEAR REGRESSION RESULTS FOR WEIGHT AS A FUNCTION OF DISPLACEMENT AND THE NUMBER OF CYLINDERS

STEP	REGRESSION ESTIMATE	R^2	SE
1	Weight = 510.58 · Cylinders (172.74)	0.985	463.17
2	Weight = 3.8901 · Displacement +344.68 · Cylinders (11.78) (24.08)	0.989	405.02
3	Weight = 6.5210 Displacement + 26.507· Cylinders+ 1548.6 (20.30) (1.09) (15.02)	0.993	330.43

Notes to Table:

The figures in parentheses (below the regression coefficients) are values of the statistic. R^2 is the coefficient of multiple determination. SE is the standard error of the estimate.

TABLE 3-22

STEPWISE LINEAR REGRESSION RESULTS FOR DISPLACEMENT AS A FUNCTION OF WEIGHT AND THE NUMBER OF CYLINDERS

STEP	REGRESSION ESTIMATE	R^2	SE
1	Displacement = 0.08319 · Weight (129.74)	0.974	51.688
2	Displacement = 0.11895 · Weight - 138.82 (437.99) (13.49)	0.982	43.618
3	Displacement = 0.07364 · Weight + 32.315 · Cylinders - 205.00 (20.30) (15.61) (22.04)	0.988	35.113

Notes to Table:

The figures in parentheses (below the regression coefficients) are values of the statistic. R^2 is the coefficient of multiple determination. SE is the standard error of the estimate.

TABLE 3-23

STEPWISE LINEAR REGRESSIONS RESULTS FOR THE NUMBER OF CYLINDERS AS A FUNCTION OF WEIGHT AND DISPLACEMENT

STEP	REGRESSION ESTIMATE	R^2	SE
1	Cylinders = 0.00193 · Weight (172.74)	0.985	0.9004
2	Cylinders = 0.00140 · Weight + 2.0478 (28.18) (10.82)	0.988	0.8024
3	Cylinders = 0.00010 · Weight + 0.01094 Displacement + 3.5660 (1.10) (15.61) (19.73)	0.992	0.6460

Notes to Table:

The figures in parenthesis (below the regression coefficients) are values of the statistic. R^2 is the coefficient of multiple determination. SE is the standard error of the estimate.

Implications of the Analysis of Variance and Stepwise Linear Regression Results

This section will explain the implications of the analysis of variance and stepwise linear regression findings. The analysis of variance results will be used to evaluate in detail the candidate design factor for inclusion in the classification scheme, while the regression results will be used to assess the interchangeability of the various factors. The actual vehicle classification design will follow directly from this discussion.

The control by cylinders analysis of variance clearly shows that for the idle modes the type of exhaust control device (air or non-air) does have a very significant effect on the concentration of HC and CO emissions from 1966-1970 vehicles. This fact is further substantiated by the ARB data (Table 3-10 and 3-11) and the age by cylinders analysis of variance, where control appears as a covariate. In all cases, the F-statistics indicate the control effect to be significant at a level considerably below 0.01. The picture is not so clear, however, for the low and high cruise modes. While the control effect remains significant for HC (see Tables 3-5, 6, 13 , 14), it loses significance for CO (Tables 3-8, 9, 16, 17). Thus, control appears to be a good candidate for inclusion in the idle mode classification scheme, only.

The results from the age by cylinders analysis of variance indicate that vehicle age is a highly significant factor in determining all key mode emission concentrations. The F-statistics displayed in Tables 3-12 through 3-17 show the age effect to be significantly different from zero at the 0.01 level for both HC and CO emissions.

In addition, based on the multiple comparison tests (Table 3-19), it appears that for the most part, the various age groups are fairly distinct. While there are some cases where two out of the three cell means do not differ significantly, these do not seem to fall into any particular pattern, suggesting that, for all practical purposes, the three age groups can be considered to be different from one another.

While the analysis of variance results for the cylinders effect are not as obvious as they were for age, it appears that this effect is also very important in explaining emission concentrations. For every age by cylinders case but one, idle CO, the cylinders effect was significant at least at the 0.05 level. For idle CO, the cylinders interaction effect, however, was significant, thus necessitating a breakdown by cylinders. The homogeneous cylinder subsets results, on the other hand, show that although the cylinders effect is significant some groups of cylinder means are not different and may be lumped together. Based on those results, it appears that in the pre-1966 age group six and eight cylinder engines have similar emission proportions and in the post-1970 age group just the opposite is true, four and six cylinder engines are similar. In the 1966 - 1970 age group, there does not seem to be any apparent pattern, and hence, four, six, and eight cylinder engines could be considered separately.

Finally, the stepwise linear regression results demonstrate that any of the three design factors considered, weight, displacement, and cylinder number, can be explained, with approximately ninety-nine percent accuracy, as a linear combination of the other two. Therefore, if for some reason one of the design engine characteristics cannot be assessed directly, a very good estimate could still be obtained based on those factors which can be determined.

Classification Design

As stated before, the actual vehicle classification design used in the development of emission standards follows almost directly from the discussion of the analysis of variance results above. However, two additional considerations were also taken into account. First, from both an operational and technical stand point, it was decided that the formulation of separate classification schemes for HC and CO was not desirable, Second, for 1966 - 1970 vehicles a distinction was made between air and non air vehicles at idle. This was found to be more efficient than differentiating between engine displacement primarily because very few four cylinder 1966 - 1970 vehicles were equipped with air pumps.

Based on these considerations the vehicle classification design finally selected was as follows:

Idle

Pre-1966	-	(4 cylinders), (6 and 8 cylinders)
1966-1970	-	(air), (non-air)
Post-1970	-	(4 cylinders), (6 and 8 cylinders)

Low and High Cruise

Pre-1966	-	(4 cylinders), (6 and 8 cylinders)
1966-1970	-	(4 cylinders), (6 and 8 cylinders)
Post-1970	-	(4 cylinders), (6 and 8 cylinders)*

It should also be noted that twelve cylinder engines are implicitly considered to be grouped with the eights.

* The analysis also indicated the need to provide specific standards for 1971-1974 vehicles equipped with air pumps. Unfortunately, the data base did not contain information on air pump equipped vehicles (specifically 1973-1974) and therefore, engineering estimates were required.

3.5 EMISSIONS STANDARD DEVELOPMENT

The design of effective emission standards required the consideration of a number of complex factors. The following highlights the basic approach used in the study.

- Emission standards were developed based on a consideration of the interaction between individual modes and emission species.
- Optimal rejection levels were based on cost-effectiveness considerations within individual engine classifications. Emission standards designed to reject nearly equal levels across defined engine classifications.
- No special consideration was given to any particular mode. All emission standards were determined by cost-effective analysis.
- Emission standards designed with an emphasis on HC reductions (specific emission weighing factors are: HC - 0.6, CO - 0.1, NOx - 0.3).
- Vehicle loaded modes were rank ordered as a function of weighted emission reductions.
- Loaded mode standards were developed, for a given rejection level, based on maximum weighted CVS emission reduction.
- The emission reduction effectiveness results were developed from vehicles receiving a complete tune up.
- Vehicles failing a single mode (e.g., idle) were subject to the repair of all detectable maladjustments and malfunctions.
- Unique pass/fail criteria were established for each age and engine classification.
- A total of 36 different emission standards were required to optimally characterize the vehicle population (3 modes x 2 emissions x 3 age groups x 2 engine classes).*

An important feature of emission standards determination is the effect of interactions between the modes and emissions, i.e., a vehicle may be rejected for multiple standard violations. Setting a rejection level of 20 percent for each mode and emission would result in a total

* In addition, separate standards were specified for air pump and non air pump equipped vehicles and for NOx emissions (1971-1974 vehicles).

rejection fraction far greater than 20 percent. If vehicular emissions were completely consistant, (i.e., if the third most highly emitting car in idle HC were also the third most highly emitting car in the other five modes), then this procedure would work. The distribution of vehicle emissions, however, is much more complex. Table 3-24 illustrates this confounding for a sample of empirical data. For example, vehicle No. 234 had HC emissions lower than vehicle 227 while its CO emissions were substantially higher.

If the emission and modal distributions were totally random then one could take the statistical union of the six rejection fractions to arrive at the total rejection level, (for example, the union of six 20 percent probabilities is 73.8%). Unfortunately, this assumption is not valid since the various modes and emissions are not independent of each other. Because the cost-effectiveness relationship between the modes and emissions is difficult to characterize analytically, (e.g., using linear programming) it was decided to use the actual empirical data directly in developing key mode emission values.

TABLE 3-24

MODAL INTERACTIONS FOR SAMPLE IDLE DATA (1966-1970 VEHICLES)

	IDLE			
VEHICLE NO.	HC (PPM)	CO (%)	NOx (PPM)	
601	2031	8.86	47.8	Ranked according to weighted CVS emissions
234	862.3	4.77	59.7	
262	485.4	4.31	75.7	
263	435.8	6.55	38.5	
197	614.6	1.48	179.7	
227	1094.6	1.46	43.8	

The technique used in estimating the emission standards was designed to account for these basic interactions. The existence of multiple interactions indicates why computer analysis of the data is not only convenient but essential. The impact of these interactions on the cutpoints is to act in opposition to the effect of increasing the number of modes. That is, if interactions never occured (if when a vehicle was rejected by one mode it was not rejected by another) then one would expect that doubling the number of modes (the number of criteria for rejecting a car) would halve the contribution of each mode in terms of the net rejection fraction. For example, a 50 percent rejection rate for idle CO would become a 25 percent rejection rate for idle CO and idle HC each when they are both used. However, the existence of interactions serves to moderate this effect. Instead of 25 percent for each of the two modes, 35 percent may be the actual rejection fraction in each mode since some of the cars will be rejected for failing both idle CO and idle HC. These considerations are systematically evaluated in the analysis.

The cutpoint optimization procedure begins by assuming an initial set of values. The initial values are determined so that the rejection level is some given value (i.e., 20 percent). This initialization procedure is, itself, complex enough to require the use of a computer program. Once the starting values have been computed and entered, the program estimates the changes in effectiveness that would result from increasing or decreasing each of the cutpoints. These changes result from altering the composition of the population of rejected vehicles. The object is to identify those vehicles with the highest CVS emission larger rejection fractions. This phenomenon can be attributed to the fact that some vehicles in the population are "tuned" to low emissions and consequently their adjustment to manufacturer's specifications will result in an actual increase in emissions.

Cost as well as emission reduction performance play an important role in establishing optimal emission standards. The relevant costs here are the explicit and implicit costs to implement the program. Explicit costs include expenditures to construct facilities and to perform specific inspection/maintenance operations. Implicit costs are less tangible and include the time the vehicle owner is involved in related inspection/maintenance activities. For this study only the explicit costs associated with initial investment and operating expenses were directly incorporated into the calculations. However, the impact of implicit program costs on rejection rates are investigated and reported in the section on cost analysis. In general, the incorporation of social costs into the evaluation will tend to decrease the optimal vehicle rejection level.

A representative plot of the program costs as a function of rejection rate is also shown in Figure 3-6. Typically, these costs are linearly related to rejection rate starting with an initial investment for R=0. It should be noted, however, that the average cost per vehicle tends to decline as rejection rate is increased. This is because of the lower average costs for maintenance (vehicles with lower emissions tend to require fewer repairs).

Figure 3-6 also features a plot of the desired effectiveness cost ratio. As can be seen it rises rapidly as R increases, reaches a maximum and subsequently declines. The maximum ratio corresponds to the optimal rejection rate. This point also corresponds to the largest distance between the effectiveness and cost curves*.

Predictive Analysis

The primary purpose of TRW's Economic Effectivesness Model is to serve as a research and design tool for assessing the long term implications of various inspection/maintenance alternatives. The development of the model required a detailed specification of the numerous relationships governing the inspection/maintenance process. Figure 3-7 outlines the essential features of the present model.

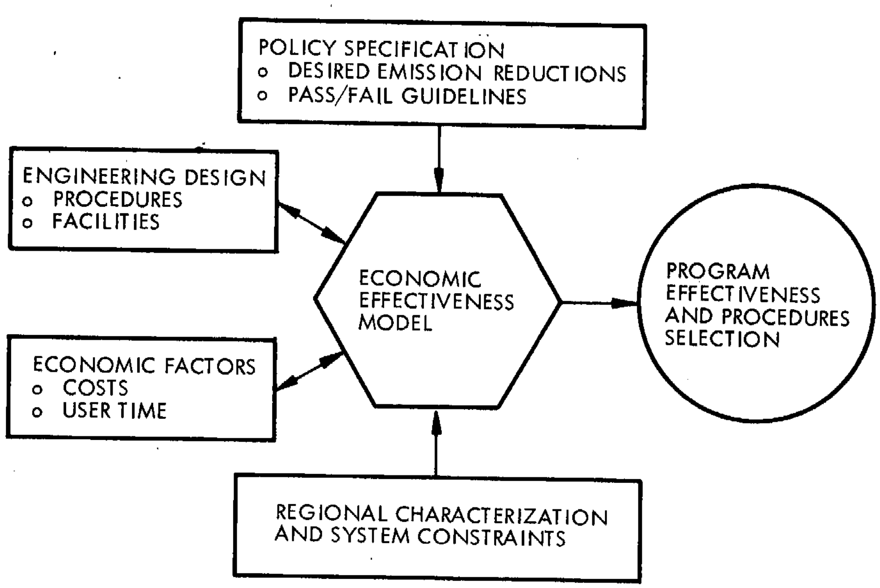

Figure 3-7. Schematic of Economic Effectiveness Model

*Appendix C presents a quasi-theoretical treatment on the relationship between program cost-effectiveness and rejection rate.

The model design is based on a blending of theoretical and empirical relationships. The simulation model can be employed for not only measuring the economic-effectiveness of various inspection/maintenance strategies but also in specifying the system design. Some of the more significant design tradeoffs include:

1) Emission and engine standards for identifying and rejecting malfunctioning vehicles.

2) Extent and frequency of adopted inspection/maintenance procedures.

3) Design of state inspection lanes including their number and location.

Since the impact of inspection/maintenance may vary as a function of vehicle type and age, the vehicle population is partitioned into four control types; uncontrolled vehicles (pre-1966), 1966 - 1970 controlled vehicles, 1971 - 1974 controlled vehicles, and post-1974 vehicles.* This classification scheme permits the specification and evaluation of unique inspection standards for each control type.

The model "bookkeeps" the emission levels for each type and combines them to form aggregate levels for the entire population. The composition of the aggregate fleet changes over time as new cars are introduced into the population and older cars leave. Consequently, the importance of the post-1970 vehicles grows with time. This dynamic state of the vehicle population underscores the need for long term predictive analysis in arriving at effective emission standards. The reader is encouraged to review TRW's Cape-13 report [6] to obtain more information on the model's structure and capabilities.

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* This classification scheme is relevant for California vehicles only. For other states the uncontrolled group extends to pre-1968 vehicles.

4.0 KEY MODE EMISSION STANDARDS

This section presents the results from the study. First, the emission inspection criteria are presented for the various vehicle classification groups. Next, the calculated performance estimates are given as a function of vehicle rejection rate. These estimates reveal the optimal rejection rates for each group and for the total population. An analysis of the impact of omission and commission errors is provided for the optimal emission standards. A detailed evaluation is given on establishing NOx emission standards and procedures for 1971 - 1974 vehicles. This analysis in turn leads to the development of emission standard procedures for post-1974 vehicles. The developed emission standards are reexamined in light of establishing potential retest criteria. The impact of the defined standards on program performance are then forecasted over a five year interval. Finally, a cost analysis is presented on the various elements of the program.

4.1 EMISSION INSPECTION CRITERIA

Tables 4-1 through 4-9 present the developed key mode emission standards for the various vehicle classifications. These standards, using the methodology outlined in Section 3.5, depict the relationship between specific modal signature levels and the resultant vehicle rejection rates. For example, Tables 4-1 through 4-3 show the cutpoint to rejection level relationship for pre 1966 vehicles. This sub-population has been divided into two engine displacement groups (4 and 6 or 8 cylinders).

TABLE 4-1

IDLE MODE EMISSION STANDARDS FOR PRE-1966 VEHICLES

REJECTION FRACTION	4 CYLINDERS *			6 or 8 CYLINDERS		
(%)	HC (PPM)	CO (%)	NO_x (PPM)	HC (PPM)	CO (%)	NO_x (PPM)
0	4000	11.0	200	4000	11.5	1000
10	3000	10.0	200	3000	11.0	1000
20	2000	9.0	200	2000	10.0	1000
30	1500	8.0	200	1400	9.0	1000
40	1250	7.5	200	1200	8.0	1000
50	1000	7.0	200	1000	7.5	1000
60	950	6.5	200	900	7.0	1000
70	800	6.0	200	750	6.5	1000
80	650	5.0	200	600	6.0	1000
90	500	4.0	200	350	5.0	1000
100	400	3.0	200	150	4.0	1000

* Pre 1968-Vehicles

TABLE 4-2

LOW CRUISE EMISSION STANDARDS FOR PRE-1966 VEHICLES

REJECTION FRACTION	4 CYLINDERS*			6 or 8 CYLINDERS		
(%)	HC (PPM)	CO (%)	NO_x (PPM)	HC (PPM)	CO (%)	NO_x (PPM)
0	2500	10.0	2500	3000	12.0	3500
10	2000	9.5	2500	1000	9.0	3500
20	1500	9.0	2500	750	7.0	3500
30	1000	8.5	2500	625	6.5	3500
40	850	8.0	2500	525	6.0	3500
50	750	7.5	2500	475	5.5	3500
60	700	7.0	2500	450	5.0	3500
70	600	6.5	2500	400	4.5	3500
80	500	5.0	2500	375	4.0	3500
90	400	4.0	2500	275	3.5	3500
100	300	3.0	2500	250	2.0	3500

* Pre-1968 Vehicles

TABLE 4-3

HIGH CRUISE EMISSION STANDARDS FOR PRE-1966 VEHICLES

REJECTION FRACTION	4 CYLINDERS *			6 or 8 CYLINDERS		
(%)	HC (PPM)	CO (%)	NO_x (PPM)	HC (PPM)	CO (%)	NO_x (PPM)
0	2000	8.0	3500	2500	10.0	4000
10	1500	7.0	3500	1000	8.0	4000
20	1000	6.0	2500	500	6.0	4000
30	800	5.0	3500	450	5.5	4000
40	600	4.0	3500	375	5.0	4000
50	550	3.75	3500	350	4.5	4000
60	500	3.5	3500	325	4.0	4000
70	450	3.0	3500	300	3.5	4000
80	400	2.0	3500	275	3.0	4000
90	300	1.5	3500	250	2.5	4000
100	200	1.0	3500	200	2.0	4000

* Pre-1968 Vehicles

TABLE 4-4

IDLE MODE EMISSION STANDARDS FOR 1966 - 1970 VEHICLES

REJECTION FRACTION	VEHICLES WITH AIR PUMPS			VEHICLES WITHOUT AIR PUMPS		
(%)	HC (PPM)	CO (%)	NO_x (PPM)	HC (PPM)	CO (%)	NO_x (PPM)
0	900	8.0	175	2000	10.0	500
10	800	7.5	175	1000	9.0	500
20	750	7.0	175	750	8.0	500
30	500	4.0	175	600	7.75	500
40	260	3.5	175	500	7.25	500
50	250	3.0	175	450	7.0	500
60	240	2.6	175	400	6.5	500
70	230	2.5	175	300	6.25	500
80	160	2.4	175	250	6.0	500
90	150	1.5	175	225	5.0	500
100	100	0.8	175	150	3.0	500

TABLE 4-5

LOW CRUISE EMISSION STANDARDS FOR 1966-1970 VEHICLES

REJECTION FACTION (%)	4 Cylinders HC (ppm)	4 Cylinders CO (%)	4 Cylinders NOx (ppm)	6 or 8 Cylinders HC (ppm)	6 or 8 Cylinders CO (%)	6 or 8 Cylinders NOx (ppm)
0	500	6.0	1500	600	4.5	4000
10	400	5.5	1500	550	4.0	4000
20	370	5.0	1500	520	3.3	4000
30	360	3.5	1500	500	2.6	4000
40	350	2.0	1500	490	2.4	4000
50	340	1.9	1500	480	2.2	4000
60	330	1.8	1500	470	2.0	4000
70	300	1.7	1500	450	1.8	4000
80	200	1.6	1500	250	1.6	4000
90	175	1.5	1500	200	1.0	4000
100	100	1.0	1500	150	0.8	4000

TABLE 4-6

HIGH CRUISE EMISSION STANDARDS FOR 1966-1970 VEHICLES

REJECTION FRACTION (%)	4 Cylinders			6 or 8 Cylinders		
	HC (ppm)	CO (%)	NOx (ppm)	HC (ppm)	CO (%)	NOx (ppm)
0	400	5.0	4000	1000	5.0	5000
10	350	4.0	4000	500	4.5	5000
20	340	3.5	4000	300	3.75	5000
30	330	3.0	4000	250	3.25	5000
40	320	2.5	4000	225	3.0	5000
50	310	2.0	4000	200	2.5	5000
60	300	1.8	4000	180	2.3	5000
70	250	1.7	4000	170	2.1	5000
80	140	1.6	4000	160	2.0	5000
90	175	1.5	4000	150	1.5	5000
1000	100	1.0	4000	100	1.0	5000

TABLE 4-7

IDLE EMISSION STANDARDS FOR 1971-1974 VEHICLES*

REJECTION FACTION	4 Cylinders			6 or 8 Cylinders		
(%)	HC (ppm)	CO (%)	NOx (ppm)	HC (ppm)	CO (%)	NOx (ppm)
0	700	10.0	250	700	9.0	500
10	600	9.0	250	600	8.0	500
20	550	8.0	250	500	7.0	500
30	500	7.0	250	400	6.5	500
40	450	6.5	250	300	6.0	500
50	400	6.0	250	250	4.5	500
60	350	5.5	250	200	3.5	500
70	300	5.0	250	175	2.0	500
80	250	4.0	250	150	1.5	500
90	200	3.5	250	125	1.0	500
100	150	3.0	250	50	0.75	500

* Vehicles without an air pump. Data set limited to 1971 - 1972 vehicles.

TABLE 4-8

LOW CRUISE STANDARDS FOR 1971-1974 VEHICLES*

REJECTION FRACTION (%)	4 CYLINDERS			6 or 8 CYLINDERS		
	HC (ppm)	CO (%)	NOx (ppm)	HC (ppm)	CO (%)	NOx (ppm)
0	500	8.0	4000	500	4.0	3500
10	400	7.0	4000	300	2.0	3500
20	375	5.5	4000	275	1.5	3500
30	350	5.0	4000	250	1.25	3500
40	325	4.5	4000	225	1.0	3500
50	300	4.0	4000	200	0.8	3500
60	275	2.5	4000	175	0.7	3500
70	250	2.0	4000	150	0.6	3500
80	200	1.5	4000	125	0.5	3500
90	150	1.25	4000	100	0.4	3500
100	100	1.0	4000	75	0.2	3500

* Vehicles without an air pump. Data set limited to 1971 - 1972 vehicles.

TABLE 4-9

HIGH CRUISE EMISSION STANDARDS FOR 1971-1974 VEHICLES*

REJECTION FRACTION	4 CYLINDERS			6 or 8 CYLINDERS		
	HC	CO	NOx	HC	CO	NOx
(%)	(ppm)	(%)	(ppm)	(ppm)	(%)	(ppm)
0	400	7.0	5000	400	4.0	4000
10	350	5.0	5000	300	2.0	4000
20	300	4.0	5000	250	1.5	4000
30	250	3.0	5000	200	1.25	4000
40	240	2.5	5000	180	1.0	4000
50	230	2.0	5000	160	0.8	4000
60	220	1.75	5000	150	0.7	4000
70	200	1.5	5000	140	0.6	4000
80	175	1.25	5000	120	0.5	4000
90	150	1.0	5000	100	0.4	4000
100	100	0.75	5000	50	0.2	4000

* Standards designed for vehicles without an air pump. Data set limited to 1971-1972 vehicles.

For the latter group, the optimal combination of loaded mode standards for a 30 percent rejection level are as follows:

	HC (ppm)	CO (%)	NOx (ppm)
Idle	1400	9.0	1000
Low cruise	625	6.5	3500
High cruise	450	5.5	4000

These standards reflect the total set of interactions between the various operating modes and emission signatures. Although NOx emission standards are present for all pre-1970 vehicles, they have been designed not to reject any vehicles in reasonable operating condition. This requirement exists because of the general inverse relationship between HC, CO and NOx emissions. That is, the reduction of HC, CO through engine repair often tends to increase NOx emissions.* It was also found that no effective signatures exist for detecting NOx related engine malfunctions for this population group. This combination of factors precluded the establishment of NOx standards for pre-1970 vehicles. A more detailed discussion of these factors along with procedures for establishing NOx emission standards for 1971 - 1974 vehicles is given in Section 4.4.

The loaded mode standards generated for the 1966 - 1970 vehicles differ somewhat in format from the pre-1966 vehicles. For idle emissions a distinction is made between vehicles equipped with air pumps and those without. This is necessary because at idle, the air pump dilutes the exhaust mixture. Statistical analysis of idle emissions clearly

* This observation is directed towards pre-1966 vehicles that have not been retrofitted with vacuum spark disconnect kits and 1966 - 1970 vehicles retrofitted with EGR systems. Since limited data exists for either case it is difficult to provide a quantitative assessment on the impact of repair and resultant emission levels.

showed this trend as illustrated in Table 3-6. The impact of the air pump on cruise mode emissions is less significant (Table 3-7) and therefore, a different sub-class was not specified.

Lastly, the emission standards for 1971-1974 vehicles are substantially lower (for comparible rejection rates) than either the pre-1966 and 1966-1970 groups. This can be attributed to the lower overall emission levels for this class of vehicles (See Table 3-2) and the influence of emission deterioration. Unfortunately, the emissions data base used in developing these standards did not contain data on 1973 or 1974 model years and consequently these results must be viewed as preliminary. This is especially the case relative to the reintroduction of air pumps on 1973 and 1974 model year vehicles. The analysis has already shown the importance of distinguishing between air and non-air 1966-1970 vehicles at idle. While the data base contained no relevent data on 1971 - 1974 air pump equiped vehicles a preliminary set of emission standards at idle for this class has been developed and is presented below:

	Air Pump 1971-1974 Vehicles
HC(ppm)	150
CO(%)	2.0

It is recommended, moreover, that additional emissions and diagnostic data on 200 1973 and 1974 vehicles be obtained and incorporated into a revised analysis of 1971-1974 vehicles.

4.2 COST-EFFECTIVENESS ANALYSIS

The techniques outlined in Section 3.5 were used in conjunction with basic emissions and cost data to determine the optimal level of vehicle rejection for a given set of emission standards. Figures 4-1 through 4-3 show effectiveness and cost-effectiveness results for the three age classifications. As can be seen, these empirical results closely relate to the theoretical descriptions depicted in Figure 3-6. Figure 4-1 presents performance estimates for combined 4, 6 and 8 cylinder pre-1966 vehicles, respectively. While the maximum effectiveness results occur at about 80 percent rejection level, the optimal cost-effectiveness points are at the 30 percent level. These substantial differences in vehicular rejections clearly underscore the need for considering both effectiveness and costs in arriving at the optimal rejection level. Similar trends are also shown in Figures 4-2 and 4-3. The performance curves for the 1966 - 1970 vehicles have been aggregated to avoid unnecessary complexity.

The effectiveness-cost results for all age and engine groups have been tabularized and are given in Tables 4-10 through 4-14. The tables include the following parameters:

- Average emission levels for pre-maintained vehicles
- Average percentage emission reduction due to maintenance for entire population
- Combined emission reduction using emission weighting factors
- Effectiveness cost ratio expressed in terms of weighted emission reductions divided by total program costs.*

The average emission levels at zero rejection are for the "as received" vehicle population. The values given for other rejection levels reflect the impact of maintenance weighted over the entire population. For example, a 30 percent rejection level for 1966 - 1970 vehicles (Table 4-12) yields emission reductions of 11.2%, 8.7% and -2.2% for HC, CO and NOx, respectively.

* The reported emission reductions for all vehicle classifications have been combined into a single figure of effectiveness using the emission weighting factors developed from the Cape-13 Study C3. (i.e., HC = 0.6, CO = 0.1, NOx = 0.3).

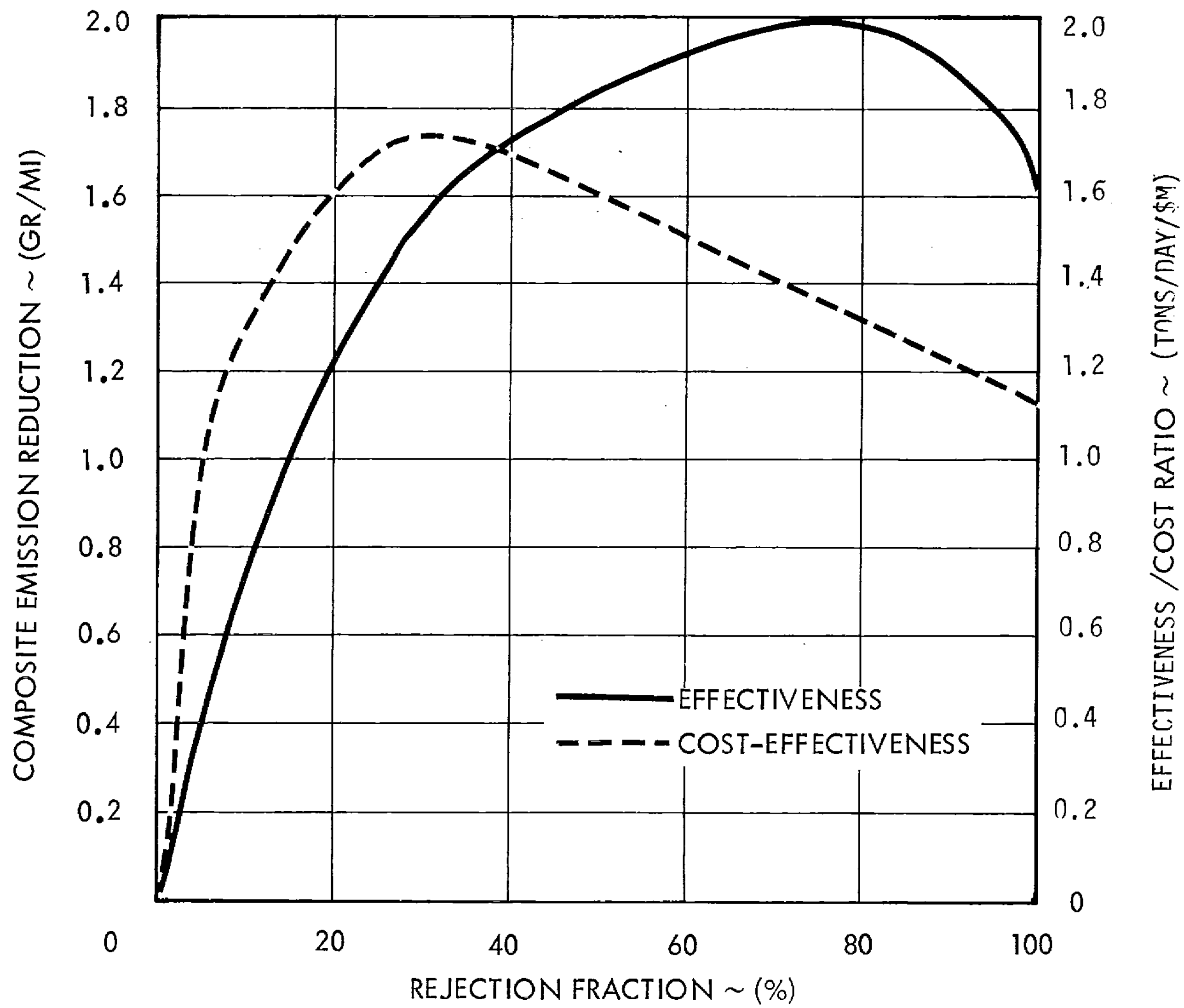


Figure 4-1. Program Performance for Pre-1966 Vehicles

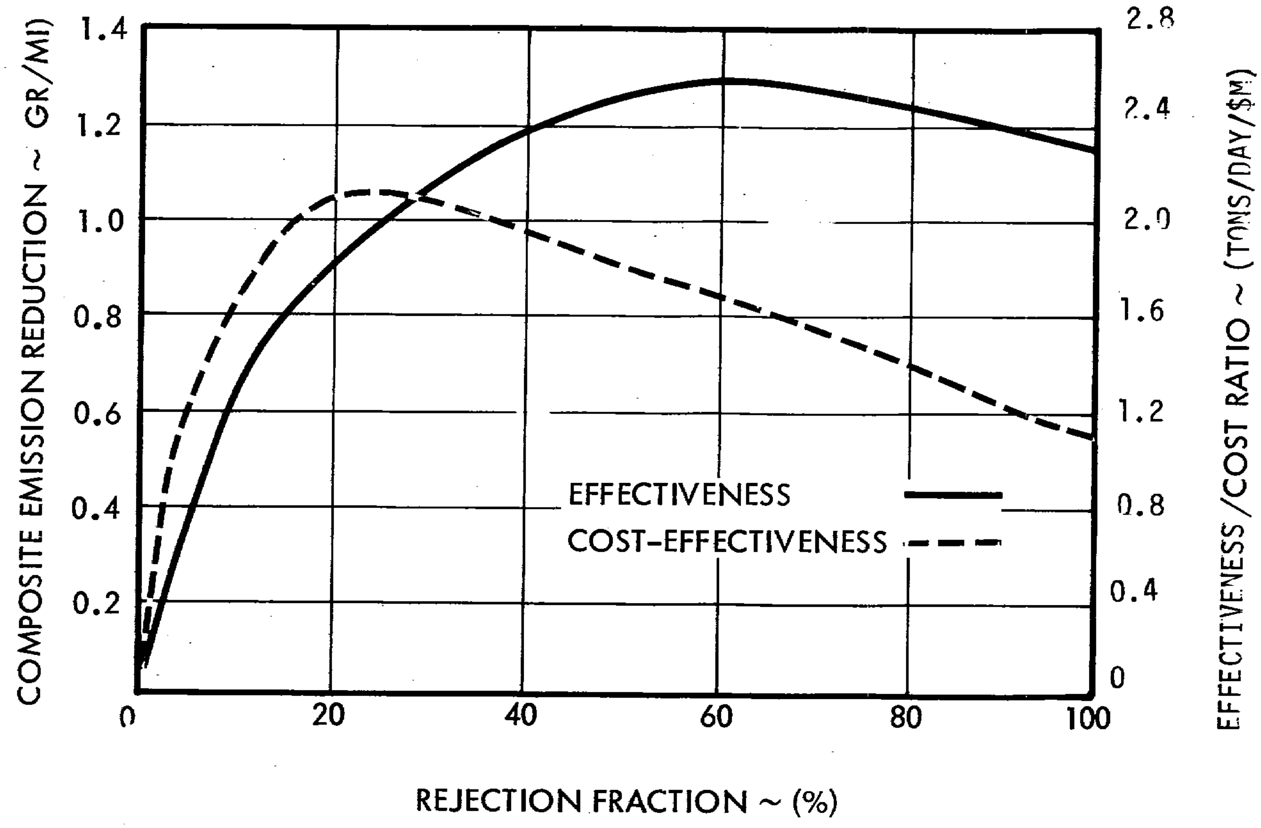


Figure 4-2. Program Performance for 1966-1970 Vehicles

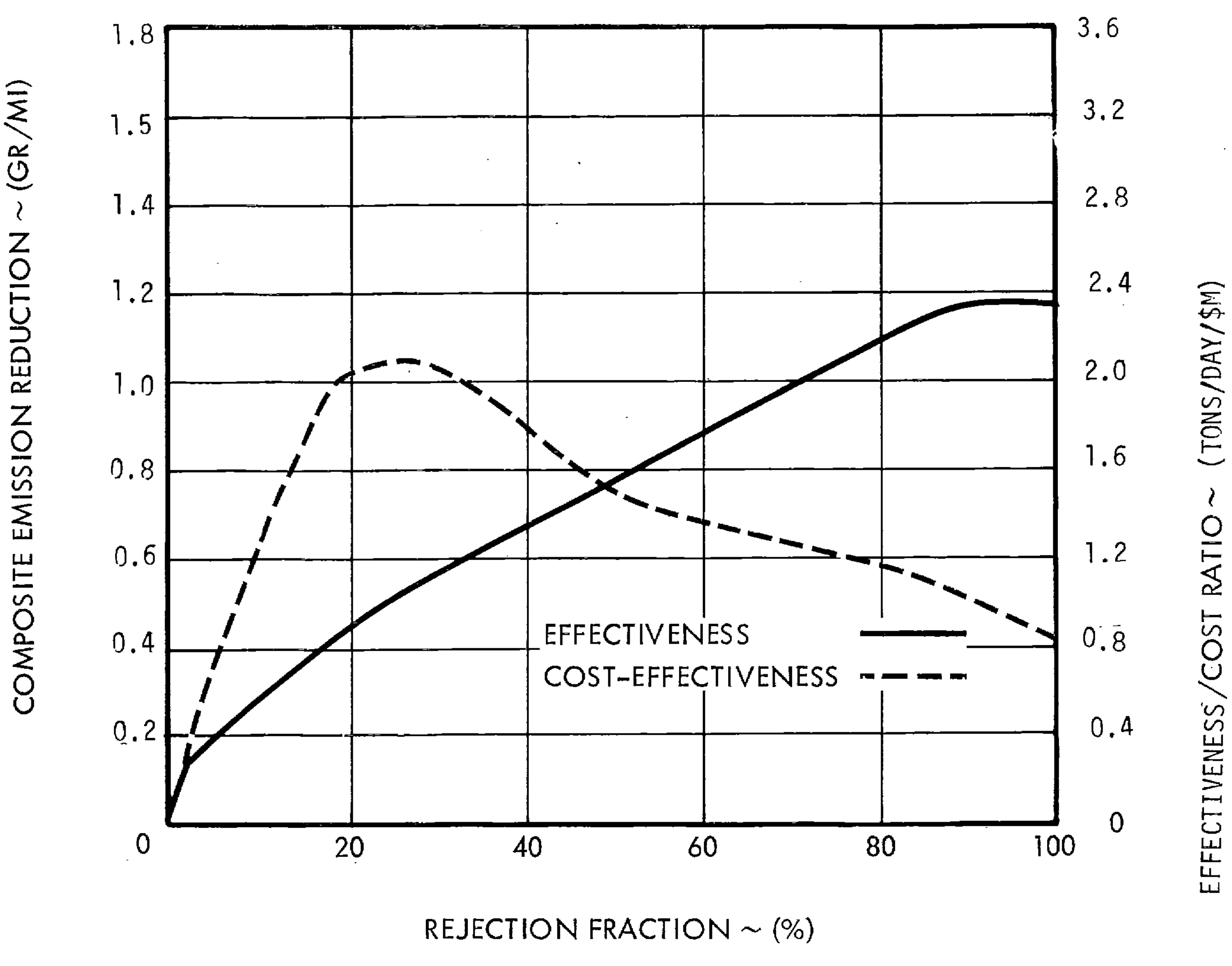


Figure 4-3. Program Performance for 1971-1974 Vehicles

TABLE 4-10

INSPECTION/MAINTENANCE PROGRAM PERFORMANCE Pre-1966 4 CYLINDER VEHICLES

REJECTION FRACTION (%)	AVERAGE EMISSION LEVELS (gr/mi)			AVERAGE EMISSION REDUCTION (%)			COMBINED REDUCTION		EFFECTIVENESS/ COST RATIO
	HC	CO	NO_x	HC	CO	NO_x	(gr/mi)	(tons/day)	(tons/day/$M)
0	12.78	88.8	2.79	0	0	0	0	0	0
10	11.37	78.6	2.85	11.0	11.5	-2.0	1.85	1.32	3.41
20	9.16	78.8	2.67	28.3	11.2	4.3	2.31	2.30	3.82
30	8.87	77.7	2.66	30.6	12.5	4.7	3.50	2.51	2.68
40	8.76	76.8	2.70	31.4	13.6	3.3	3.64	2.61	2.72
50	8.78	75.7	2.79	31.3	14.8	0	3.71	2.66	2.75
60	8.81	75.4	2.83	31.1	15.0	-1.3	3.71	2.66	2.69
70	9.11	76.3	2.82	28.7	14.0	-0.9	3.44	2.47	2.45
80	8.99	74.6	2.85	30.0	16.0	-1.9	3.68	2.64	2.60
90	8.84	74.4	2.89	30.8	16.2	-3.5	3.77	2.71	2.49
100	8.99	76.8	2.82	29.6	13.5	-1.0	3.46	2.48	2.24

TABLE 4 - 11

INSPECTION/MAINTENANCE PROGRAM PERFORMANCE FOR PRE 1966 6 and 8 CYLINDER VEHICLES

REJECTION FRACTION (%)	AVERAGE EMISSION LEVELS (gr/mi) HC	CO	NO_x	AVERAGE EMISSION REDUCTION (%) HC	CO	NO_x	COMBINED REDUCTION (gr/mi)	(tons/day)	EFFECTIVENESS/ COST RATIO (tons/day/$M)
0	11.11	125.0	3.70	0	0	0	0	0	0
10	10.15	122.2	3.74	8.6	2.3	-1.1	0.84	8.5	1.38
20	10.02	120.3	3.72	9.8	3.8	-0.5	1.12	11.3	1.42
30	9.83	117.0	3.74	11.5	6.4	-1.1	1.56	15.8	1.59
40	9.71	115.7	3.78	12.6	7.4	-2.1	1.75	17.7	1.50
50	9.67	115.1	3.77	13.0	7.9	-2.1	1.83	18.6	1.32
60	9.67	115.0	3.80	13.0	8.0	-2.9	1.83	18.6	1.17
70	9.62	113.7	3.82	13.4	9.0	-3.3	2.00	20.1	1.13
80	9.62	113.7	3.84	13.4	9.1	-3.8	1.98	20.1	1.02
90	9.71	114.0	3.88	12.6	8.8	-4.9	1.89	19.1	0.89
100	9.85	115.5	3.96	11.3	7.6	-7.0	1.63	16.5	0.71

TABLE 4 - 12

INSPECTION/MAINTENANCE PROGRAM PERFORMANCE FOR 1966 - 1970 VEHICLES

REJECTION FRACTION (%)	AVERAGE EMISSION LEVELS (gr/mi)			AVERAGE EMISSION REDUCTION (%)			COMBINED REDUCTION		EFFECTIVENESS/ COST RATIO
	HC	CO	NO_x	HC	CO	NO_x	(gr/mi)	(tons/day)	(tons/day/$M)
0	6.40	79.3	5.94	0	0	0	0	0	0
10	5.88	75.4	6.00	8.1	4.8	-1.0	.68	25.5	1.72
20	5.77	73.6	6.02	9.8	7.1	-1.2	.92	34.5	1.99
30	5.68	72.4	6.07	11.2	8.7	-2.2	1.08	40.4	2.10
40	5.66	72.3	6.04	11.6	8.8	-1.6	1.11	41.6	1.91
50	5.64	71.4	6.00	11.9	9.9	-1.0	1.23	46.1	1.87
60	5.65	71.4	5.92	11.8	10.0	0.4	1.25	46.8	1.69
70	5.61	71.8	5.95	12.4	9.4	-0.1	1.22	45.9	1.34
80	5.64	71.8	5.94	11.9	9.5	0.1	1.21	45.3	1.39
90	5.67	71.6	5.97	11.5	9.7	-0.5	1.20	44.9	1.27
100	5.69	71.9	6.00	11.1	9.4	-1.0	1.15	43.1	1.12

TABLE 4-13

INSPECTION/MAINTENANCE PROGRAM PERFORMANCE FOR 1971-1974 4 CYLINDER VEHICLES

REJECTION FRACTION (%)	AVERAGE EMISSION LEVELS (gr/mi)			AVERAGE EMISSION REDUCTION (%)			COMBINED REDUCTION		EFFECTIVENESS/ COST RATIO
	HC	CO	NO_x	HC	CO	NO_x	(gr/mi)	(tons/day)	(tons/day/$M)
0	4.15	52.4	4.61	0	0	0	0	0	0
10	3.99	50.3	4.63	3.9	4.1	-0.5	0.30	1.4	0.50
20	3.83	47.8	4.65	7.7	8.8	-1.0	0.64	6.1	1.78
30	3.70	47.0	4.57	10.8	10.3	0.5	0.82	10.1	2.43
40	3.74	47.4	4.54	9.9	9.6	1.4	0.77	8.8	1.79
50	3.69	46.7	4.50	11.1	10.9	2.3	0.88	11.6	2.08
60	3.67	46.6	4.50	11.4	11.1	2.3	0.90	12.2	1.83
70	3.65	47.0	4.55	12.2	10.4	1.2	0.86	11.0	1.46
80	3.56	45.3	4.36	14.2	13.6	5.3	1.14	19.5	2.46
90	3.44	44.6	4.35	17.3	15.0	5.6	1.28	24.7	2.74
100	3.50	45.1	4.39	15.8	13.9	4.8	1.19	21.1	1.96

TABLE 4 - 14

INSPECTION/MAINTENANCE PROGRAM PERFORMANCE FOR 1971-1974 6 and 8 CYLINDER VEHICLES

REJECTION FRACTION (%)	AVERAGE EMISSION LEVELS (gr/mi)			AVERAGE EMISSION REDUCTION (%)			COMBINED REDUCTION		EFFECTIVENESS/ COST RATIO (tons/day/$M)
	HC	CO	NO_x	HC	CO	NO_x	(gr/mi)	(tons/day)	
0	4.27	59.3	5.68	0	0	0	0	0	0
10	4.19	56.6	5.69	1.8	4.5	-0.3	0.32	19.2	1.38
20	4.11	55.1	5.66	3.7	7.1	0.3	0.52	31.9	1.48
30	4.12	54.6	5.68	3.6	8.0	-0.1	0.56	34.2	1.22
40	4.12	54.5	5.67	3.4	8.1	0.2	0.57	35.0	1.01
50	4.02	52.4	5.67	5.9	11.6	0.0	0.84	51.5	1.22
60	4.03	52.5	5.67	5.5	11.4	0.0	0.83	50.5	1.00
70	4.10	52.1	5.59	3.9	12.1	1.5	0.85	51.8	.90
80	4.05	51.3	5.56	5.0	13.5	2.0	0.97	59.1	.92
90	4.03	50.7	5.57	5.5	14.6	1.8	1.04	63.3	.91
100	4.07	50.8	5.62	4.7	14.4	0.9	0.99	60.3	.79

Table 4-15 summarizes the emission standards for optimal rejection levels. It should be noted that each combination of engine class and age grouping does not necessarily result in the same percentage level. These distributional effects are illustrated in Table 4-16. Shown are the rejection levels by grouping for three different cases: 1) "as received", 2) post-maintenance and 3) after one year of deterioration. The average overall rejection rate for the vehicle population is approximately 30 percent.* Applying the same standards after maintenance yields a rejection level of approximately five percent (i.e., 15 percent of those vehicles which undergo maintenance will fail the subsequent re-test). Finally, Table 4-16 also shows the impact of deterioration on rejection level. In general, emissions for the population tend to return to their "as received" state after one year of deterioration. This observation should be tempered with the fact that the deterioration data was developed under "laboratory conditions" and, therefore, does not totally reflect the dynamic state of the the vehicle population (i.e., vehicle attrition and owner tampering).

To place the developed standards in perspective Table 4-17 gives the distribution of the vehicle population by age and displacement as of June 1974. Clearly the accuracy of the standards is more important for those classifications that contain larger percentages of vehicles. Fortunately, the data base, at least from a numerical standpoint, was designed to contain more of these class of vehicles (i.e., sample size selected according to vehicle distribution). It should be further noted that the relative importance of the pre-1966 vehicles will continue to decline over time and consequently the primary focus should be on the new model year vehicles.

* This estimate is based on a composite of the TRW, Olson-ARB, and ARB data sets. The estimated rejection rate using the TRW data base alone is approximately 35 percent.

TABLE 4-15

EMISSION STANDARDS FOR OPTIMAL REJECTION LEVEL[a]

	Pre-1966		1966-1970		1971-1974		
	4 Cylinders	6 or 8 Cylinders[b]	4 Cylinders	6 or 8 Cylinders[b]	4 Cylinders	6 or 8 Cylinders[b]	
			AIR(d)	NON-AIR(d)		NON-AIR(e)	AIR(e)
Idle							
HC(ppm)	2000	1400	500	600	500	500	150
CO(%)	9.0	9.0	4.0	7.75	7.0	7.0	2.0
NOx(ppm) (c)	200	1000	175	500	250	500	200
Low Cruise							
HC(ppm)	1500	625	360	500	350	275	
CO(%)	9.0	6.5	3.5	2.6	5.0	1.5	
NOx(ppm) (c)	2500	3500	1500	4000	2500(c)	2500(c)	
High Cruise							
HC(ppm)	1000	450	330	250	250	250	
CO(%)	6.0	5.5	3.0	3.25	3.0	1.5	
NOx(ppm) (c)	2500	4000	4000	5000	5000	4000	

a. Standards designed to fail approximately 30% of vehicle population
b. Category includes eight cylinders and greater
c. NOx standards were designed not to fail any vehicle, however, a NOx screening standard for 1971 - 1974 vehicles was set at 2500 ppm (low cruise)
d. Unique standards for air and non-air vehicles have been established at idle only for 1966 - 1970 population segment
e. Unique standards for air and non-air vehicles may also be necessary for 1971 - 1974 population segment. For this group a distinction is made between small and large engines for non-air equipped vehicles.

TABLE 4-16

VEHICLE REJECTION FACTORS BY POPULATION CLASSIFICATION

As Received

Year \ CYL	4	6	8
Pre 1966	40%	32%	
1966-1970	46%	29%	
1971-1974	33%	23%	

Post-tune

Year \ CYL	4	6	8
Pre 1966	0%	5%	
1966-1970	15%	10%	
1971-1974	8%	1%	

Post Deterioration

Year \ CYL	4	6	8
Pre 1966	20%	20%	
1966-1970	50%	35%	
1971-1974	35%	25%	

TABLE 4-17

DISTRIBUTION OF VEHICLE POPULATION BY AGE AND DISPLACEMENT*

	4 Cylinders	6 Cylinders	8 Cylinders	TOTAL
Pre-1966	2%	3%	14%	19%
1966-1970	7%	4%	29%	40%
1971-1974	10%	3%	28%	41%
Totals	19%	10%	71%	100%

* For June 1974

Lastly, the relative distribution of modal rejection levels for the defined emission standards are presented in Table 4-18. Shown for each age group and engine class combination is the proportion of vehicles rejected by each of the three modes expressed as a percentage of both the total vehicle population and the rejected vehicle population in that group. The table illustrates the emphasis placed on each of the modes in rejecting vehicles. As is apparent, the contribution due to the idle modes remains approximately constant at 60 percent, while the contribution due to the cruise modes declines steadily as later model vehicles are considered. This decline is a function of the decreasing incidence of interaction between the modes in newer cars.

Table 4-18 provides a measure of the amount of interactions that occured between modes. For older cars there is much greater interaction; i.e., if a vehicle is rejected at idle it is also very likely to be emitting unacceptably in the cruise modes. Whereas, in the case of late model cars the major contribution of the idle modes is more evident in the lower incidence of rejection due to the cruise modes. This characteristic is illustrated in the late model cars by the decline in rejection interactions*.

*An analysis which compares the impact of the developed standards (idle only) vis-a-vis the current ANB PVI standards is given in Appendix D.

TABLE 4-18

MODAL EMISSION REJECTION DISTRIBUTION BY VEHICLE AGE*

	PRE 1966	1966-1970	1971-1974
IDLE	27.3/67.2	20.3/62.3	19.5/60.6
LOW CRUISE	14.7/36.0	14.9/46.0	11.4/35.4
HIGH CRUISE	23.3/57.4	9.4/46.8	8.2/35.3

* Two percentage numbers were given for each cell of the matrix. The first number represents the percentage rejected for a given model group and mode for the total population. For example, 27.3 percent of all Pre-1966 vehicles failed the idle standard. The second number reports the percentage distribution for those vehicles failing one or more modes. That is, for Pre-1966 vehiclex 67.2 percent of the vehicles failing the loaded mode test fail at idle.

4.3 ESTIMATES OF OMISSION AND COMMISSION ERRORS

As noted earlier, an emission inspection program is plagued by two basic problems:

Errors of omission	-	Those vehicles passing the inspection that have engine maladjustments or malfunctions.
Errors of commission	-	Those vehicles failing the inspection that are in a good state of repair.

Errors of omissions tend to reduce the effectiveness of the inspection program where as errors of commission tend to increase program costs. Both effects were detected in the emissions data base used in this study.

Table 4-19 shows the impact of these errors on inspection accuracy for pre-1966, 1966 - 1970 and 1971 - 1974 vehicles, respectively. For measuring the extent of omission and commission errors, four common engine maladjustments and malfunctions were selected for consideration -- idle rpm, timing, PCV valve and air cleaner. For illustrative purposes consider the case for idle rmp. Out of the 148 vehicles surveyed a total of 19 were found to have an rpm setting lower than the preferred engine specification criteria (i.e., 50 rpm). The criterion was applied only to those vehicles with rpm settings lower than specification, since the adjustment of idle rpm downward tends to increase HC and CO emissions. Here, the term "rejected" refers to number of vehicles failing the loaded mode test while the term failed refers to the number of actual engine maladjustments and malfunctions. The application of the loaded mode standards to the same set of vehicles (148) identified 10 vehicles with rpm maladjustments. For this example, the number of commission errors were 36 (49-13) whereas, the number of omission errors were 6 (19-13). These results indicate rather good performance in detecting rpm maladjustments for pre-1966 vehicles.

Table 4-19 also highlights the effectiveness of the loaded mode standards in identifying PCV valve malfunctions for 1966 - 1970 vehicles. Here, 47 vehicles failed the emission test of which 11 were found to have excessive blockage (i.e., 1.5 CFM). These results indicated 36 commission (57-11) and 8 (19-11) omission errors.

The effectiveness of the key mode standards to detect two or more engine maladjustments and malfunctions (in various combinations) out of a total of ten is depicted in Table 4-19.* For 1971 - 1974 vehicles a total of 21 out of the 34 that failed the test were found to have two or more maladjustments or malfunctions. This yields a 38.2 percent error of commission and a 67.2 percent error of omissions.

In summary, the developed key mode emission standards were shown to be reasonably effective in identifying vehicles with engine maladjustments and malfunctions. The extent of commission errors for the three vehicle age groups averaged about 25 percent for the ten engine parameters. The level of omission errors for the same classes amounts to nearly 65 percent across all engine parameters. On an individual component basis the key mode emission signatures are somewhat less effective in detecting specific failures. This general ineffectiveness at the individual component level can be attributed to the relative high noise to signal ratio associated with interpreting specific emission signatures.

* TRW's Cape-13 program identified ten basic engine failures that had a significant influence on emission. Using the criteria of two or more component failures is justified on the grounds of overall cost-effectiveness.

TABLE 4-19

ANALYSIS OF OMISSION AND COMMISSION ERRORS

MODEL YEAR	PARAMETER	SAMPLE SIZE	ENGINE SPECIFICATION CRITERIA	REJECTED NO.	REJECTED PERCENT	FAILED NO.	FAILED PERCENT	FAILED AS PERCENT OF TOTAL	PERCENT OF FAILURES DETECTED
Pre 1966	Idle RPM	148	-50 RPM			19	12.8		
				49	33.1	13	26.5	8.7	68.4
	Timing	148	1.5 DEG.			57	38.5		
				49	33.1	16	32.7	10.8	28.1
	PCV	148	1.5 CFM			21	14.2		
				49	33.1	9	18.4	6.1	42.9
	Air Cleaner	148	100 DEG.			35	23.6		
				49	33.1	16	32.7	10.8	45.7
	TOTAL	148	-----			87	58.8		
				49		35	71.4	23.6	40.2
1966-1970	Idle RPM	145	-50 RPM						
				47	32.4	34 11	23.4 23.4	7.6	32.4
	Timing	145	1.5 DEG			53	36.6		
				47	32.4	19	40.4	13.1	35.8
	PCV	145	1.5 CFM			19	13.1		
				47	32.4	11	23.4	7.6	57.9
	Air Cleaner	145	100 DEG			21	14.5		
				47	32.4	8	17.0	5.5	38.1
	TOTAL	145	-------			76	52.4		
				47	32.4	29	61.7	20.0	38.2
1971-1974	Idle RPM	149	-50 RPM						
				34	22.8	26 10	17.4 29.4		
	Timing	149	1.5 DEG.			40	26.8		
				34	22.8	14	41.2	9.4	35.0
	PCV	149	1.5 CFM			43	28.9		
				34	22.8	9	26.5	6.0	20.9
	Air Cleaner	149	100 DEG.			11	7.4		
				34	22.8	7	32.4	4.7	63.6
	TOTAL	149	--------	34		64	61.8	14.1	32.8
					22.8	21	43.0		

4.4 NOx EMISSION STANDARDS AND PROCEDURES

The establishment of NOx emission standards for uncontrolled and 1966-1970 controlled vehicles poses a serious problem for two reasons. First, procedures designed to decrease NOx emissions tend to increase HC and CO emissions. Secondly, common modal emissions signatures are ineffective for diagnosing NOx related engine malfunctions. These two factors tend to negate the development of meaningful NOx emission standards for these classes of vehicles. The case of vehicles equipped with NOx control devices (i.e., post-1970 for California) indicates different trends as will be shown in the following analysis.

A basic objective in establishing NOx emission standards for post 1970 vehicles is to ascertain the operability of the NOx control systems. Since current emission signature technology can not effectively diagnose NOx control failures, another alternative is required. The approach selected involves the development of a NOx screening standard. Here, a simple key mode test is used to identify potential malfunctioning systems for subsequent direct diagnostic evaluation. These concepts are illustrated in Figure 4-4 .

Shown are emission distributions for vehicles with operating and failed NOx control systems. Typically the emission distribution for vehicles with operating NOx systems tend to be lower than for failed systems. Using these differences, a specific NOx standard can be established based on one of three criteria: Minimize errors of omission (A), Minimize total errors (B), and minimize errors of commission (C). Those vehicles failing the test could then be taken out of the production inspection lane for detailed diagnostic analysis. This screening procedure could also be applied to other advanced emission control systems (e.g., catalyst).

Figures 4-5 through 4-8 present NOx emission frequency distributions for the key modes and CVS measurements, respectively. This data was collected from a samole of 79 vehicles equipped with NOx control systems in a state of good repair. Also shown are pre and post maintenance emission levels for vehicles that were found with failed NOx emission devices. Unfortunately, the small sample size of failed vehicles (2) and the large variance in NOx emissions precludes the observation of any consistent diagnostic trends. Additional diagnostic testing is required to adequately describe the emission signature from failed NOx emission control vehicles. Based on this limited sample, however, a screening NOx standard of 2,500 ppm, as measured in low cruise, was selected for initial application. This standard will independently reject approximately ten percent of the 1971-1974 vehicle fleet.

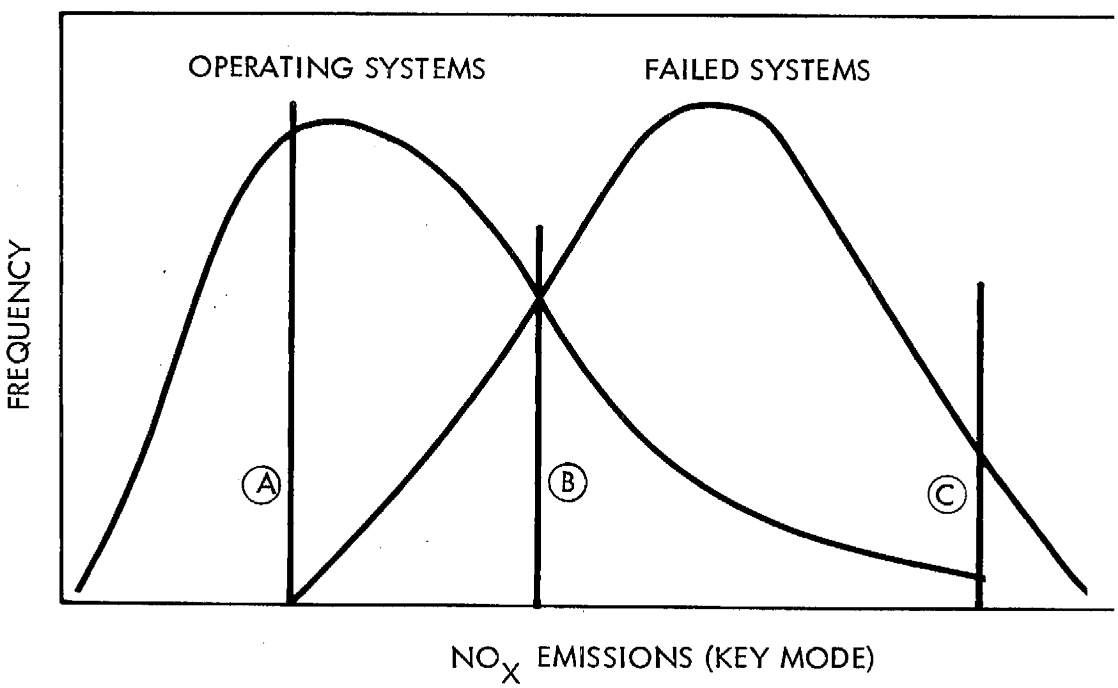


Figure 4-4. Schematic of Ideal NOx Emission Test

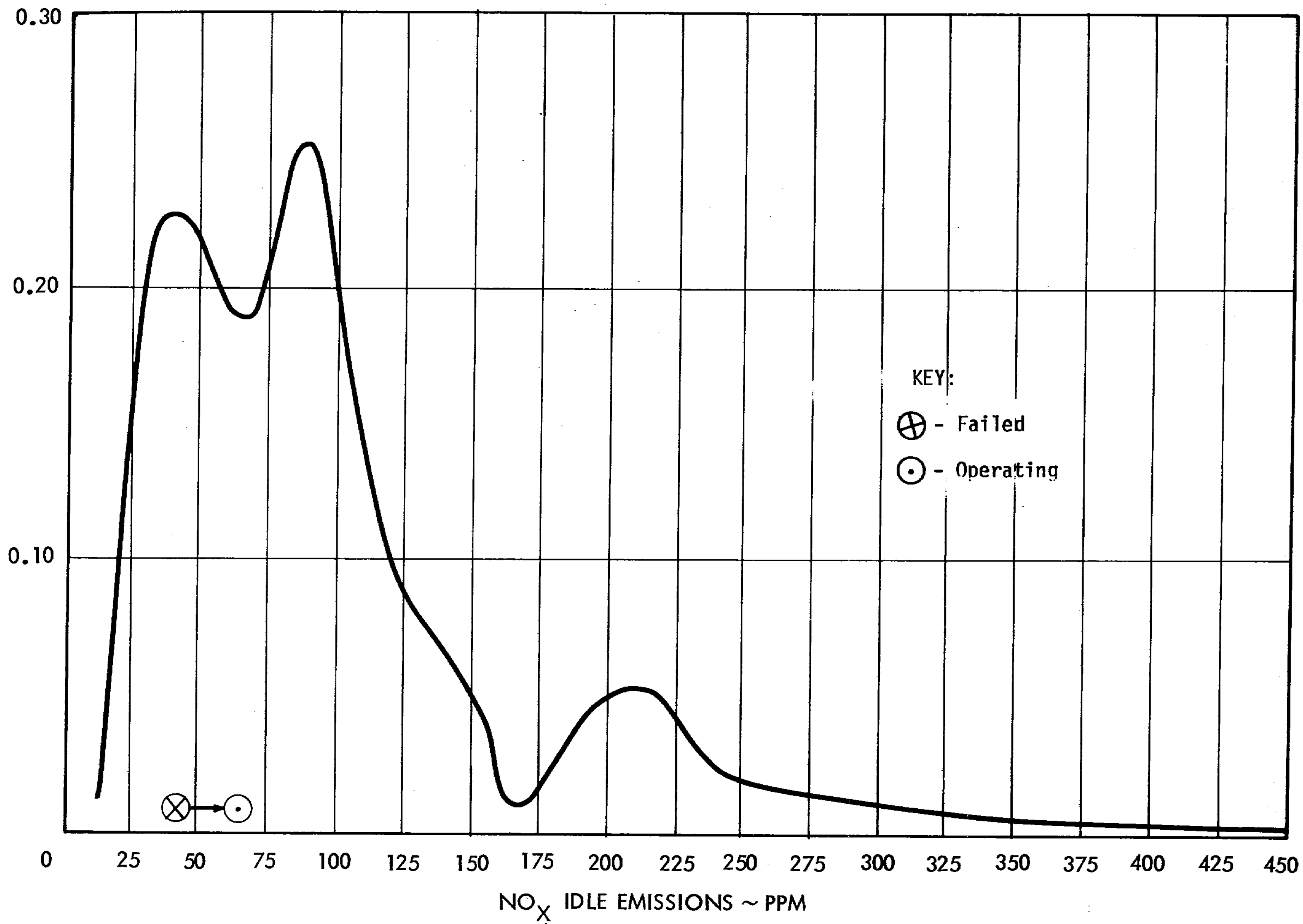


Figure 4-5. NOx Emission Distribution at Idle

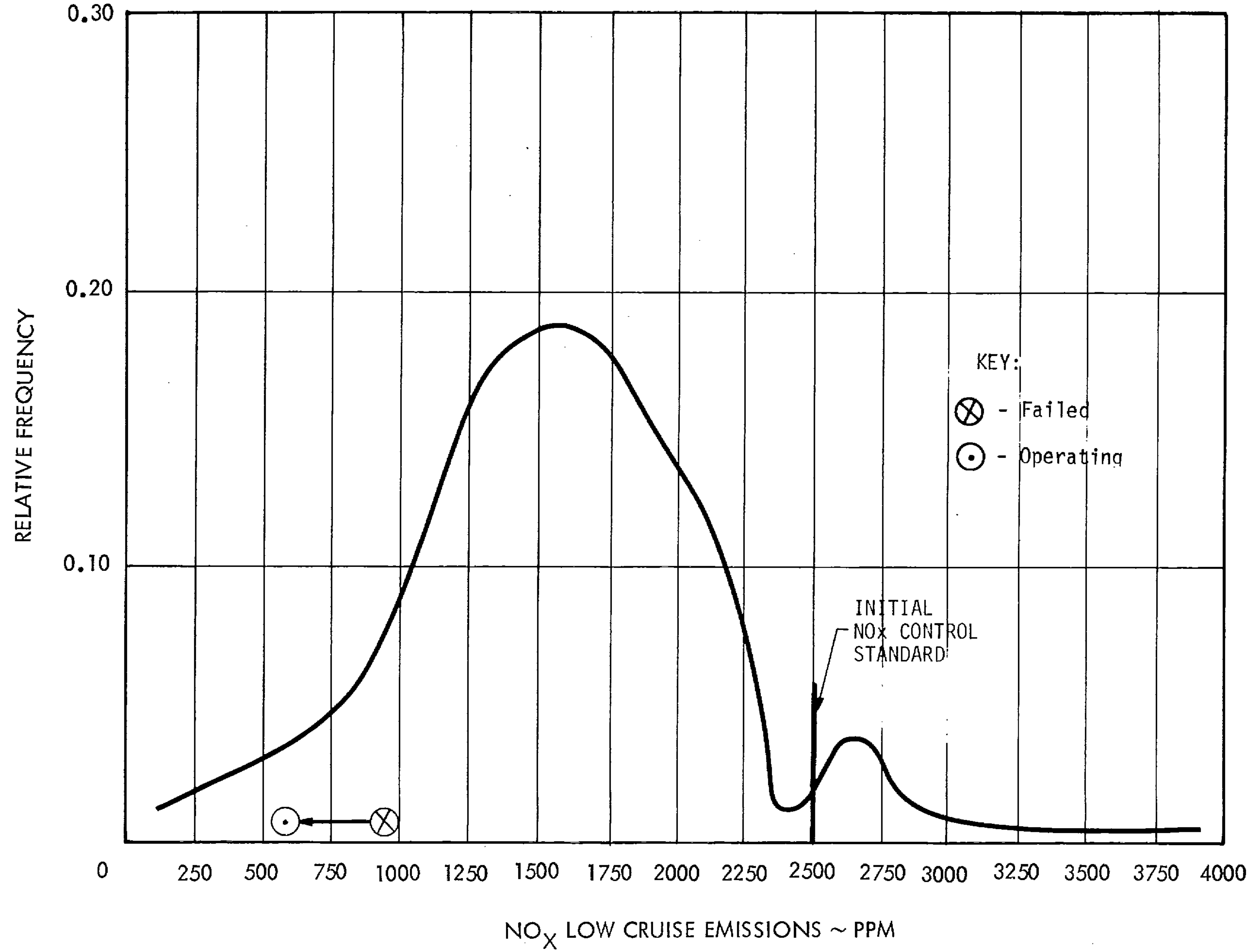


Figure 4-6. NOx Emission Distribution at Low Cruise

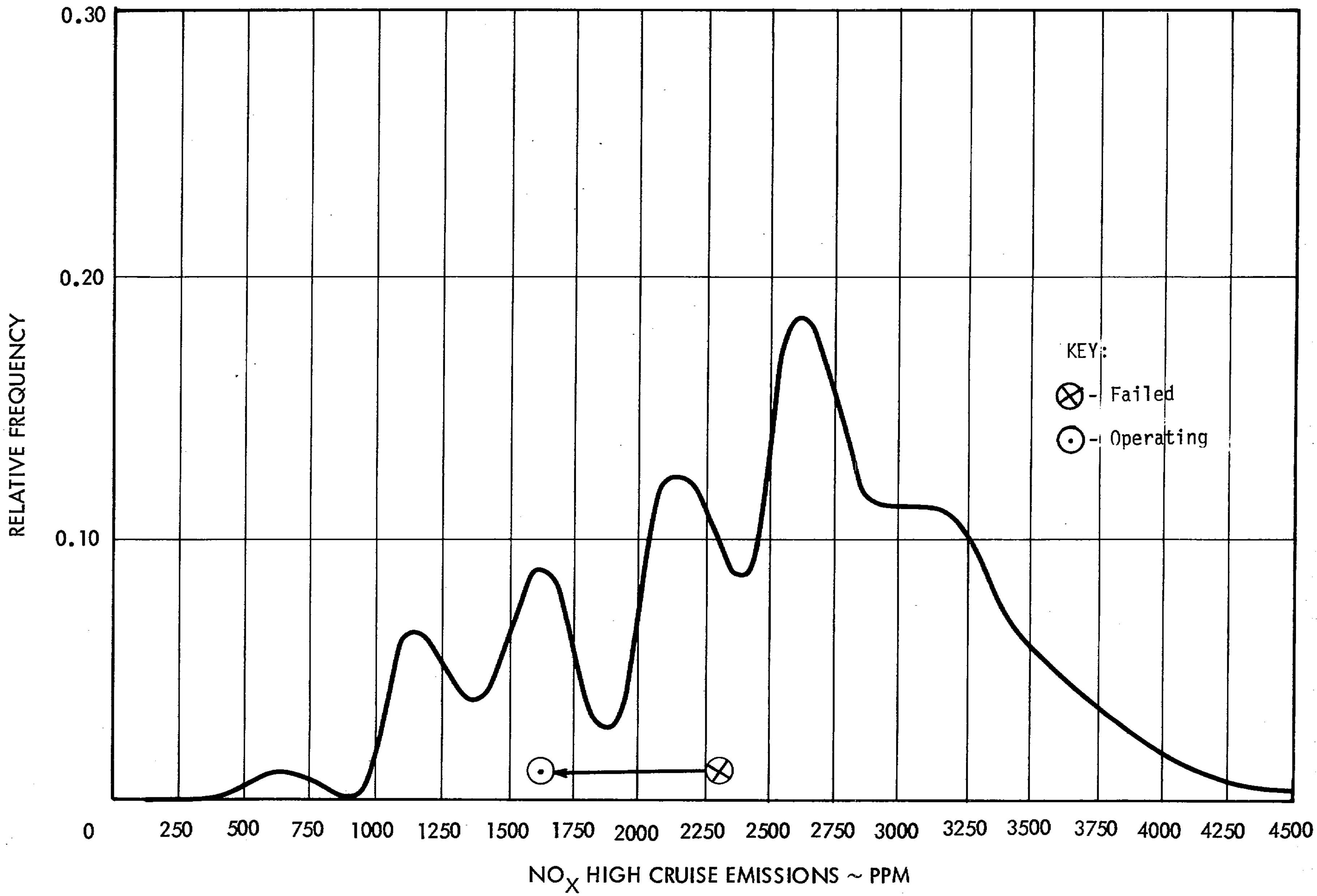


Figure 4-7. NOx Emission Distribution at High Cruise

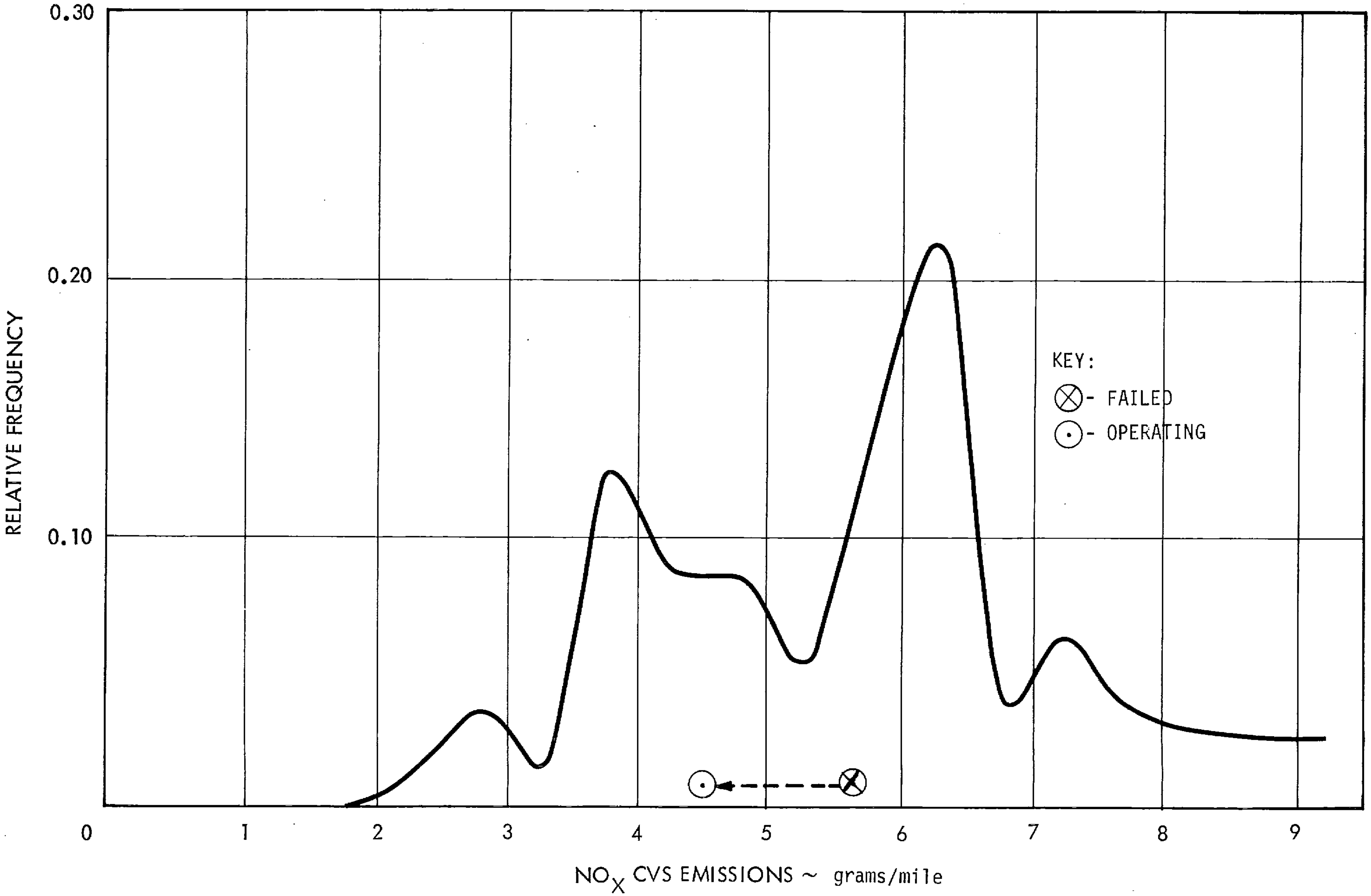


Figure 4-8. NOx CVS Emission Distribution

4.5 INSPECTION STANDARDS DEVELOPMENT FOR POST-1974 VEHICLES

Recommendations for the development of inspection standards for motor vehicles in model years after 1974 are reviewed herein. The section is divided into two parts -- "Future Motor Vehicles" and "Recommended Inspection Standards". In the first part, the power plant and control system types which are expected to make up the new vehicle populations of the future are discussed. In the second part, recommendations are made regarding the standards to be used for developing these standards.

4.5.1 Future Motor Vehicles

Federal new car emission standards have been set for model years through 1978. Consequently, relatively more is known about the probable trends in automotive power plant design through these years than in later years, and discussion has been divided accordingly, into "1975 through 1978 Model Years" and "Post - 1978 Model Years".

1975 Through 1978 Model Years

Emission standards for the certification of new cars have been set by the Federal Environmental Protection Agency (EPA) and appear in Table 4-20. These standards will be applied as indicated to the model years 1975 through 1978. The 1975 standards shown apply only to motor vehicles to be sold in California and are considered "interim" standards. In 1975, allowable new-car emissions of hydrocarbons, carbon monoxide, and nitrous oxides will each be reduced significantly from allowable levels in 1974. Levels of hydrocarbons and carbon monoxide will be further reduced for new cars in 1976 through 1978, and nitrous oxides emission levels will be further reduced for 1977 and 1978 models.

TABLE 4-20

FEDERAL NEW-CAR MASS EMISSION STANDARDS FOR CALIFORNIA

MODEL YEAR	CERTIFICATION TEST METHOD [b]	EMISSION STANDARDS HC	CO	GRAMS/MILES NOx
1974	CVS-C	3.4	39.0	--
	CVS-CH	3.0	28.0	3.1
1975[a]	CVS-CH	0.9	9.0	2.0
1976	CVS-CH	0.9	9.0	2.0
1977	CVS-CH	0.41	3.4	2.0
1978	CVS-CH	0.41	3.4	0.4

SOURCE: Reference 3.

a. California Interim Standards
b. CVS-C: Constant Volume Sample With Cold Start
CVS-CH: Constant Volume Sample With Both Cold and Hot Starts

The basic power plants used in 1975 through 1978 model vehicles will not differ significantly from those used in 1974. The conventional gasoline-fueled spark-ignition internal combustion engine will probably remain dominant through these years, while rotary engines (the Wankel) will remain a small percent of the total. The use of stratified charge IC engines will probably increase through these years, depending on economic factors and on whether the future emission standards remain as legislated or are relaxed.

For the 1975 model year, most automobile manufactureres are planning to market conventionally carbureted IC engines with emission controls very similar to those used in 1973 and 1974 model vehicles, but with the addition of oxidizing catalytic converters to control hydrocarbon and carbon monoxide emissions [5]. The use of these converters is definitely planned for California cars; they will probably be used also for vehicles sold elsewhere.

The control systems which are similar to the 1973 - 1974 controls are the Vacuum Spark Advance (VSAD) and Exhaust Gas Recirculation (EGR), both of which control the emissions of nitrous oxides from the engine. Both VSAD and EGR act to reduce the peak combustion temperature of the engine, thereby reducing NOx emissions directly. By preventing the distributor vacuum control to advance the spark during specific portions of engine operation, a VSAD system does reduce the rate of pressure rise in combustion of the air-fuel mixture in the cylinders, and, therefore, reduces the maximum temperature of the combusting mixture and the formation of oxides of nitrogen

By returning a small part of the exhaust gases to the intake manifold, the EGR system adds water vapor and an essentially inert gas to the air-fuel mixture entering the cylinders. Exhaust gas makes up typically 7% to 13% of the mixture entering the cylinders at maximum EGR operation. Since this portion of the total mixture does not react to a significant degree, it acts as a heat sink, and, like the VSAD system, does not allow the combusting mixture to reach as high a temperature, thereby reducing NOx emissions further.

Oxidizing catalytic converters reduce HC and CO emissions by combining the engine exhaust with additional air in the presence of a catalyst which accelerates the oxidation of the HC and CO in the exhaust to water and carbon dioxide. Major problems associated with the operation of such a system are catalyst deterioration due to contamination buildup on the catalyst surface, catalyst poisoning by leaded fuel, excessive temperature, and attrition of catalytic material. However, tests recently run by the automobile manufacturers have indicated that oxidizing catalystic converters may perform satisfactorily over the specified life of a motor vehicle (50,000 miles).

It should be noted that not all automobile manufacturers will use catalytic converters in 1975. Three manufacturers in particular -- Honda, Toyo Kogyo (Mazda), and Daimler-Benz --have shown that they are able to meet 1976 HC and CO standards with noncatalyst systems [5]. These companies will use noncatalyst emission control systems in at least part of their 1975 and 1976 new car fleets.

It is not yet completely clear what most automobile manufacturers will do for the 1976 model year. The federal new car emission standard for NOx is the same as the 1975 California interim standard, so it does not appear necessary for manufacturers selling cars in California in 1975 to use different NOx controls in 1976. However, HC and CO standards are over 50% lower in 1976 than they were for California in 1975. The systems to be used by most manufacturers to meet this more severe standard will probably be similar in most cases to the systems used in 1975.

The lower NOx standard in 1977 and 1978 will probably require the use of a significantly different system to control NOx than the systems used in 1975 and 1976. There are three systems most often discussed for these model years: the dual catalyst, the three-way catalyst with feedback air-fuel ratio control, and the thermal reactor. These systems are briefly described in the following paragraphs:

Dual Catalyst. This system consists of two catalysts: an oxidizing catalyst similar to the 1975 - 1976 catalyst, to reduce HC and CO emissions; and an additional (reducing) catalyst to control NOx emissions. Although this system has met 1977 - 1978 standards under controlled conditions, there are several problems inherent in the operation of the NOx catalyst:

- The activity of the NOx catalyst deteriorates much more rapidly than the oxidizing catalyst for HC and CO control.
- Physical attrition of the NOx catalyst is a major problem.
- The system is complex and requires precise control of engine operations.

As a result, the potential of the dual catalyst system for achieving the 1977 - 1978 standards is, at least at this time, questionable.

Three-Way Catalyst. This system uses a single catalyst for controlling the emissions of all three pollutants: HC, CO, and NOx. A sensor in the exhaust stream is used in a feedback loop to the engine to control the air-fuel ratio for optimal catalyst operations. However, no data are available for evaluating the durability of the three-way catalyst or of the oxygen sensor in the exhaust environment.

Thermal Reactor. This system controls HC and CO emissions and would be used in conjunction with an NOx catalyst. This system has the same problems as the dual catalyst, with the additional disadvantage of lower fuel economy.

For controlling the conventional IC engine, the dual catalyst is at this time the favored system for meeting the 1977 - 1978 standards [3], although this situation can easily change as test data become available for the other two systems described, and as additional systems are developed.

Several engine types other than the conventional IC engine have been shown to be capable of lower NOx emissions. These include the rotary (Wankel) engine and the stratified-charge reciprocating engine. These engines have the capability for reducing NOx emissions with lower penalties in fuel economy than a modified conventional IC engine [4]. However, data for long mileage testing are not yet available, and it is questionable whether these systems can be used on large vehicles with acceptable performance.

In summary, essentially the same system will probably be used for controlling the emissions from the conventional IC engine for both the 1975 and 1976 model years. It will consist primarily of an oxidizing catalytic converter for HC and CO control, and Vacuum Spark Advance Delay and Exhaust Gas Recirculation for NOx control. Although systems currently exist which can at least come close (in short-mileage tests) to meeting the 1977 - 1978 model year new car emission standards, there are insufficient data to predict with any certainty which of these systems will be used for controlling the conventional IC engine in 1977 and 1978. Furthermore, other power plant types, such as the stratified charge engine and possibly the rotary, will make up significant portions of the new car population in 1977 and 1978, although the distribution of new car powerplants in these model years is difficult to predict at this time.

Post-1978 Model Years

The prediction of either the federal new car emission standards or the distribution of power plant types among all vehicles sold in California in the post-1978 model years is highly uncertain. The emission standards are now statutory for the model years through 1978 and may be extended or modified for the model years thereafter. Events which could affect the values of the standards are possible at any time between the present and 1978 and are also difficult to predict. An example of a recent event which could have changed the existing emission standard is the gasoline crisis in the winter of 1973 - 1974. Senate Bill 2589 was introduced, largely as a result of the gasoline crisis, and would have extended the 1975 interim standards to 1976 model year cars, would have relaxed NOx standards in 1977, and would have required the current 1977 - 1978 statutory standard in 1978. This bill passed both houses of Congress, but was vetoed by the President.

Several motor vehicle power plant design concepts have been developed (or adapted) in the last several years, and some of these may account for large portions of the new car distribution in the years after 1978. These power plant types included the following:

- stratified charge IC
- rotary (Wankel)
- diesel
- stirling cycle
- gas turbine
- electric
- hydrogen enrichment
- hybrids

It is likely that several of these will offer the conventional IC engine a serious challenge for the new car market in the coming years, although it is difficult to predict with any confidence which types or the actual distribution of power plants among the new car fleets.

4.5.2 Recommended Inspection Standards

Future motor vehicles will have relatively complex emission control systems. Because of this, it is difficult to project what the interactions will be among these systems, and it is impossible to specify an effective and equitable partitioning scheme for these new vehicles until adequate data are taken. Therefore, the following recommendations are made with regard to the initial inspection procedures to be used for 1975 model year vehicles:

HC and CO Standards. Use the standards and partitioning scheme developed in this report for HC and CO emissions for 1971 through 1974 model year vehicles, until standards specific to 1975 model year vehicles can be developed.

NOx Standards. Use the standards and partitioning scheme developed in this report for NOx emissions for 1971 through 1974 model year vehicles, until validated standards for 1971 through 1974 and 1975 model year vehicles can be developed.

Data Gathering. Run additional loaded-mode tests on approximately 200 1975 model vehicles as they are admitted for mandatory inspection, measuring emissions of HC, CO and NOx and using control device manipulations to correlate malfunctions with measured emission levels.

The application of these interim standards for new vehicles will not cause significant perturbations on overall vehicle rejection rates, since they will be in effect only a short time, and since new vehicles during this time will account for only a few percent of the total vehicle population. The same procedure should be followed during the beginning of each succeeding model year.

Emission Control System. Control device manipulations, included in the data gathering phase of the above recommendations, will involve two kinds of tests, one for HC, CO and one for NOx since the control systems used for these emissions are, for all practical purposes, discrete. Causative factors should be identified with methods typical of recent test programs.

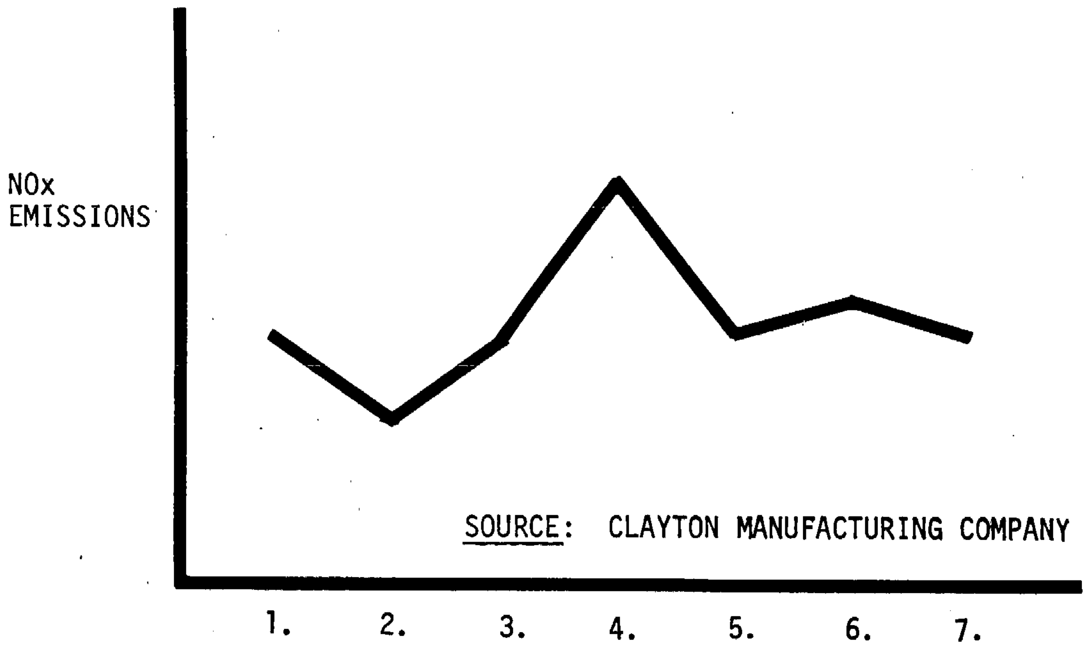
There is currently insufficient information from the maufacturers for specifying a procedure for adequately testing the functioning of the oxidizing catalytic converter to be used on 1975 cars for meeting the 1975 HC and CO new car standards. It is possible that sampling ports in the exhaust pipe upstream of the converter may be included by some manufacturers. If this is the case, inspectors can measure directly the effectiveness of a converter for removing HC and CO from the vehicle exhaust by measuring HC and CO levels upstream and downstream of the device. Another possible method that has been suggested is to short one spark plug and observe temperature and HC and CO concentration differences at the end of the exhaust pipe. (This assumes that all cylinders are firing.) Although HC concentrations out of the engine will rise significantly, no significant change in CO will result. Unfortunately, engine diagnostic information is not provided as in the case of a true key mode regime. Also, although some manufacturers permit shorting plugs, others strongly advise against it because of possible destruction of the catalyst. It is very important that any method to be used be approved by the automotive manufacturer, for obvious reasons, and it is hoped that the manufacturers will eventually have a recommendation for functionally inspecting the catalytic converter system. Furthermore, all of the above procedures require diagnostic as opposed to loaded mode analysis and are thus beyond the scope of this investigation.

As previously stated, NOx emissions from most 1975 model vehicles will be controlled primarily by VSAD and EGR systems. Preliminary laboratory investigations [4] suggested that functional tests may be run quite easily to test for malfunctions of these systems. One possible procedure is as follows:

1. Utilize NOx emission mechanism for screening potentially malfunctioning devices.
2. Observe NOx emissions in low cruise mode, holding constant throttle position and following these steps:
   a. Disconnect the distributor vacuum control device and measure NOx in low cruise mode.
   b. Reconnect distributor vacuum control.
   c. Disconnect EGR system and measure NOx emissions.
   d. Reconnect EGR.

If the VSAD and EGR systems are functioning correctly, definite perturbations are apparent in the low cruise mode. The plot of NOx emissions, Figure 4-9, illustrates an NOx emission signature taken during preliminary investigations of this type of test. When the vacuum control is disconnected, NOx emissions decrease significantly. When the EGR system is disconnected, NOx emissions increase significantly.

The reasons for these observations follow from a discussion of the operation of these devices. Since the distributor vacuum control advances in the low cruise mode, it normally causes higher peak temperatures in the combustion chamber, and, consequently, higher emissions of NOx. Thus, when the vacuum advance is disconnected, NOx emissions are reduced; if this does not happen, a malfunction in the VSAD or the vacuum control (of which VSAD can be considered a part) is indicated. Conversely, the EGR system acts to reduce NOx emissions as described in Section 4.5.1 of this report. When it is disconnected NOx emissions should increase; if they do not, a malfunction in the EGR system is indicated.



STEPS IN TEST CYCLE.

1. NORMAL OPERATION
2. VACUUM CONTROL DISCONNECTED
3. NORMAL OPERATION
4. EGR DISCONNECTED
5. NORMAL OPERATION
6. BOTH DISCONNECTED
7. NORMAL OPERATION

Figure 4-9. Candidate Test for VSAD/EGR Malfunctions

Both disconnections are relatively simple operations and the entire test should not require more than a few minutes per car. The preliminary investigation has indicated that the Low Cruise mode provides for the most pronounced perturbations in measured NOx emissions during this kind of test. The test has been run at constant speed, constant throttle, and constant vacuum, respectively, and the results seem valid for each of these three ways. However, constant throttle is the most perceptive and definitely the easiest condition to maintain and would provide for the most efficient and fastest test. While these general techniques are designed to diagnose NOx control failures - the optimum procedure definition is left for subsequent development.

An important requirement for determining effective emission control inspection standards is the cost effectiveness of corrective repair. The evaluation of cost effectiveness requires data inputs in two forms: the costs of repair in dollars and the effectiveness of repair for specific retrofit malfunctions in terms of the emission reductions per car and the aggregate emission reductions for the vehicle population. Since transmission or road speed VSAD has been predominately used during 1971 and 1972 models (some in 1970), the cost of repair expense seems nominal. Unfortunately, the cost of repair of neither HC, CO control devices, such as catalytic converters, nor NOx control devices, such as VSAD (on 1973 - 1974 models) and EGR, are presently unknown. Similarly, neither the effectiveness of the repair of control devices per se nor the effectiveness of the repair industry for performing corrective maintenance on these relatively new devices are known at present. Both cost data and effectiveness data can only be acquired during the actual operation of the inspection program. Studies heretofore made on the repair of the comparatively simple uncontrolled and controlled vehicles have indicated the need for upgrading the repair industry. It is anticipated, therefore, that the new more complex emission control technology used on late model and future vehicles may result in significantly different values of cost per unit of emission reduction for corrective maintenance.

4.6 EMISSION RE-TEST CRITERIA

The concept of establishing re-test emission standards which are more stringent than the initial inspection standards is potentially applicable to the South Coast inspection program. This concept is illustrated in Figure 4-10. Vehicles failed during the initial inspection are sent to repair facilities for adjustment. These adjustments are made to meet re-test standard Y which is lower numerically than X, the original inspection standard. After adjustment, the vehicle is re-tested with standard Y. If it fails this re-test, it is returned to the repair facility for re-adjustment. The concept is most appropriate for dealing with idle CO emissions, for the following reasons:

- Idle CO is both an emission and an engine parameter; it is solely dependent on carburetor adjustment. Other emissions are generally related to engine or equipment malfunctions.
- Idle CO emissions can usually (barring carburetor malfunctions) be adjusted continuously over a range of values, and it is, therefore, relatively easy for the repair mechanic to set idle CO emissions for meeting a particular standard. This is not true in general for other pollutant species.
- Very few repair agencies have facilities for checking emissions under load, while many can check and adjust idle CO.

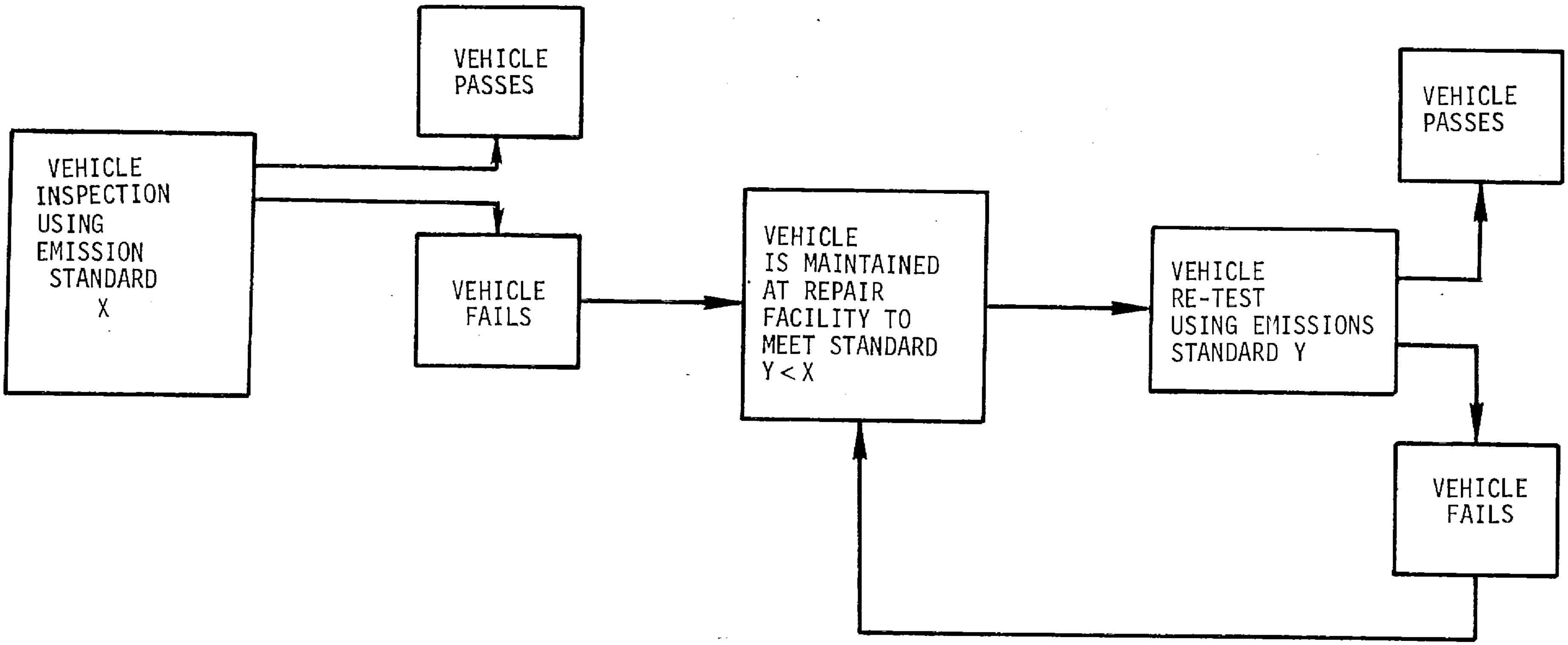


Figure 4-10. Flow Diagram for An Inspection Program Incorporating Re-Test Standards More Stringent Than Initial Inspection Standards

Advantages

- The stringent re-test standard will further reduce aggregate emissions from the vehicle population in the South Coast Air Basin.

- It will help insure that the repair facility does indeed adjust each failed vehicle for low emissions.

- It will serve to encourage the vehicle owner to obtain maintenance before the initial test or prior to the re-test inspection after failing the initial inspection.

Disadvantages

- Stringent re-test standards may lead to public relation problems. (That is, it may seem unfair to some owners that one set of standards is more stringent than another for the same pollution species.)

- It may increase the likelihood of a "ping pong" effect, in that some cars may have to go through several cycles of maintenance and re-test before passing a stringent re-test standards.

- It may result in higher costs for repair, as a result of the possible ping-pong effect and the additional requirements for idle CO.

Some of these advantages and disadvantages can be reduced to quantifiable questions and are dealt with in the following discussion. Others are subjective and, therefore, are not easily quantified. Still others are quantifiable, but the data do not currently exist for adequate analysis, and the analyses must wait until sufficient data are obtained during the course of the actual inspection program.

The quantifiable questions are the following:

- What are the effects of more stringent re-test standards on the aggregate emissions from the entire vehicle population?

- What is the cost effectiveness of using more stringent re-test standards?

Cost effectiveness is, in simple terms, determined by dividing the effectiveness in terms of the aggregate emission reductions for the entire vehicle fleet in tons per day by the cost of the inspection procedure in dollars. This expression normally lends itself to maximization. However, the costs associated with idle adjustments are, for all intents and purposes, constant with respect to the amount of idle CO emissions from a particular automobile. That is, adjusting the idle screw on a particular carburetor to 2 percent CO rather than 3 percent CO requires no more parts or mechanics labor, and therefore, the costs of the adjustments should be the same. The only exception to this will be the cases in which engine malfunctions prevent the mechanic from adjusting the idle mixture below a particular level. The malfunctions in these cases must be repaired before the vehicle can pass the re-test, and additional costs will be involved. It is expected that these cases will be rare for idle CO adjustments, however.

Since costs are essentially constant, optimum theoretical cost effectiveness will be attained when idle CO is zero. A zero idle CO adjustment is, of course, impractical, because of vehicle engineering and maintenance facility limitations. These limitations lead to the following minimums for idle CO:

Model Year Classification	Minimum Idle CO (% CO)
Pre-1966	5%
1966-1970	2%
1971-1974	1%

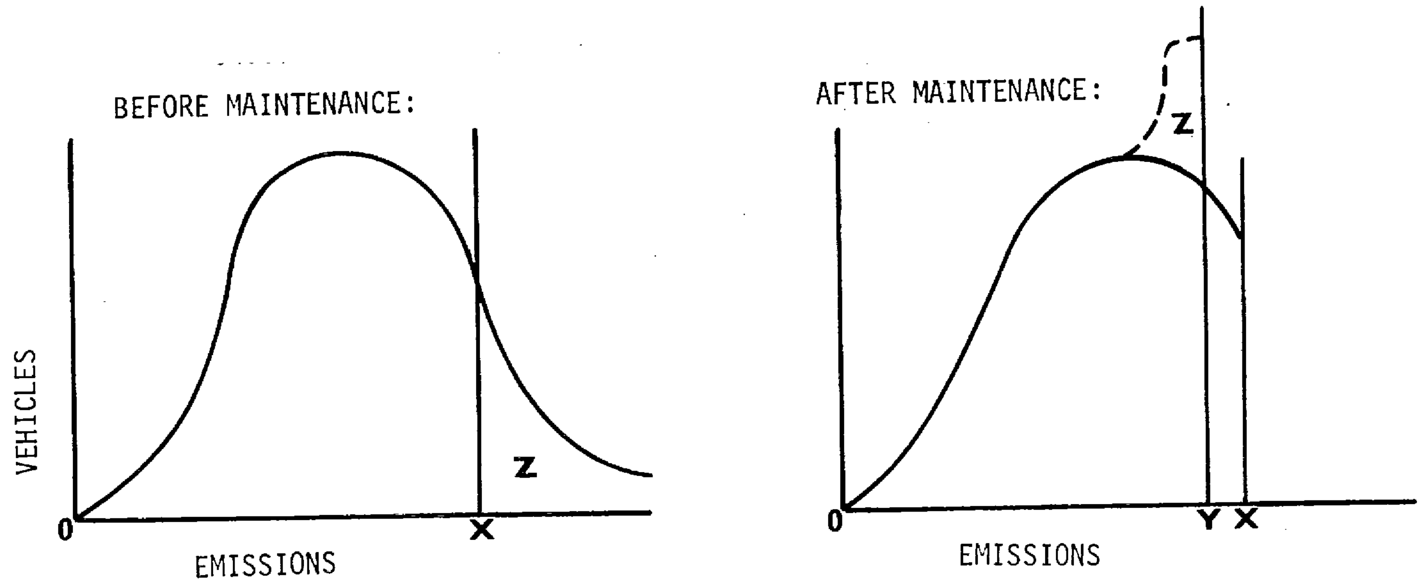
These emission levels are proposed limits below which idle CO re-test standards should not be set; they evolve from considerations of the following:

- Vehicle engineering limitations. Experienced engineering judgment indicates that the driveability of vehicles adjusted to idle emission levels below those indicated will not be acceptable.

- Maintenance facility limitations. Firsthand experience with maintenance garages in California indicates that most facilities do not have instrumentation required for accurate adjustment of idle CO to levels lower than those indicated.

Re-test standards simply should not be set at these minimum values, however, without looking at the effect of lower test standards on aggregate emissions of all three pollutants. This leads to the first of the quantifiable questions stated earlier. Figure 4-11 shows the effect of the stringent re-test standard on the distribution of emissions from the vehicle population. A number, Z, of the vehicles are failed during the initial inspection and are taken to repair facilities for adjustment. These Z vehicles are returned to the "passed" fleet at emissions level Y or less. It is likely that, especially in the case of idle CO, the repair facility will adjust the vehicle to slightly less than Y emissions (as long as Y is not the minimum idle CO level shown earlier), in order that the vehicle pass the re-test and that the customer be satisfied with engine performance. In this treatment, the actual case has been idealized for purposes of analysis with the assumption that all failed vehicles return to the "passed" fleet emitting at level Y, rather than at some continuous distribution slightly less than Y.

This is a conservative assumption, considering that one is interested in comparing the total emissions from a hypothetical set of vehicles adjusted to meet standard $Y < X$ with a hypothetical set of vehicles adjusted to meet standard $Y = X$. The error in assuming a single-value



X = INITIAL INSPECTION STANDARD
Y = RE-TEST STANDARD
Z = FAILED VEHICLES

Figure 4-11. Effect of Stringent Re-Test Standard on Vehicle Emissions Distribution

distribution will actually be the same for both comparative standards ($Y < X$ and $Y = X$) and will, therefore, cancel out.

Emission reductions due to candidate re-test standards were calculated for all three pollutants. Idle CO levels in tons per day were calculated by dividing the TRW CAPE-13 data into six subsets according to the control types discussed earlier in this report. The total vehicle population in the South Coast Air Basin was taken as five million. This population was divided into six groups according to control type, using historical vehicle population data for the air basin. Each group had a corresponding mileage factor in terms of miles per year per vehicle.

For each subset the mean values of idle CO above and below the initial inspection standards were calculated. These standards were different for each of the subsets and the retest standards were defined at 10% intervals between these initial standards and the respective lower limits discussed earlier.* An overall mean was calculated for each subset as well as means for the post-tune vehicles considering each of the 10 retest values.

It was necessary to convert the emission concentrations into absolute terms (gr/mi) in order to obtain values of tons/year. The data base provided both idle CO (%) and CVS CO (gr/mi) data for the means except that the CVS equivalents of the retest values had to be interpolated. This was done using a linear interpolation between levels at 0.0 and the mean of values above the initial inspection standard.** The equation used for converting emissions to tons/year was the following:

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* The re-test value was the post-tune value given for the idle CO level of cars which exceeded the initial inspection standard.

** The methodology used the influence coefficients developed in CAPE-13 to relate changes in idle CO to corresponding changes in CVS mass emissions.

Emissions reduction (tons/year) =

(millions of cars in subset) x (thousands of miles per year/car) x 3.02 tons per year/gram per mile) x (CO in grams per mile).

The changes in emissions of HC and NOx due to the candidate re-test standards were also calculated with the use of sensitivity factors determined for 1971 vehicles during the CAPE-13 study [6]. These coefficients are expressed in terms of the change in CVS emissions (grams per mile) per unit change in idle CO (%CO) are as follows:

	HC	CO	NOx
Pre-1966	0.44	4.03	0.21
1966-1970	0.029	4.40	0
1971-1974	0.067	6.53	-0.034

The reductions (or increases, for NOx) in these emissions in tons per day due to the respective idle CO re-test standard were calculated using the conversion equation shown for CO emissions.

The results of these calculations are shown in Appendix E. They are expressed in both tons per day and percents of total emissions from the vehicle population of the South Coast Air Basin.

These total weighted reductions have been calculated as follows:

$$WER = R_{CO} \times W_{CO} + R_{HC} \times W_{NC} - I_{NOx} \times W_{NOx}$$

where:

WER = weighted emission reduction in tons per day

R = reduction in emissions

I = increase in emissions

W = weighting factor (HC: 0.6, CO: 0.1, NOx: 0.3)

These weighted reductions were converted to weighted percent reductions with the following equation:

$$WPR = \frac{WER}{E_{CO}\ W_{CO} + E_{HC}\ W_{HC} + E_{NOx}\ W_{NOx}}$$

where:

WPR = weighted percent reduction

E = emissions in tons per day from vehicle population and the weighted percent

Figure 4-12 shows the relationship between total emission reduction and idle CO standards for the various vehicle subsets. The figure indicates that significant reductions in overall emissions from the vehicle population can be attained with the use of a stringent re-test standard for idle CO.

The recommended set of standards for re-test idle CO are presented in Table 4-21. Included in this table are the initial inspection standards for idle CO, the emission changes for the vehicle population for each pollutant species in both tons per day and percent, and the weighted total emission change in both tons per day and percent. In this table, algebraic signs have been used to differentiate the reductions in CO and HC emissions (positive) from the increases in Nox emissions (negative). The total weighted change is, then, negative.

These standards provide a significant reduction in CO and HC emissions at practically no additional cost (compared to using the initial idle CO inspection standards for re-test) and allows the repair mechanic to set idle CO at values slightly lower than the standard to insure that the vehicle will pass re-test, while maintaining acceptable driveability and customer satisfaction. The reduction in CO emissions is expected to be nearly 9.5 percent of vehicle emissions. This reduction is three times greater than the 3.2 percent to be expected from the use of the same idle CO standard for both initial inspection and re-test. The identified set of standards

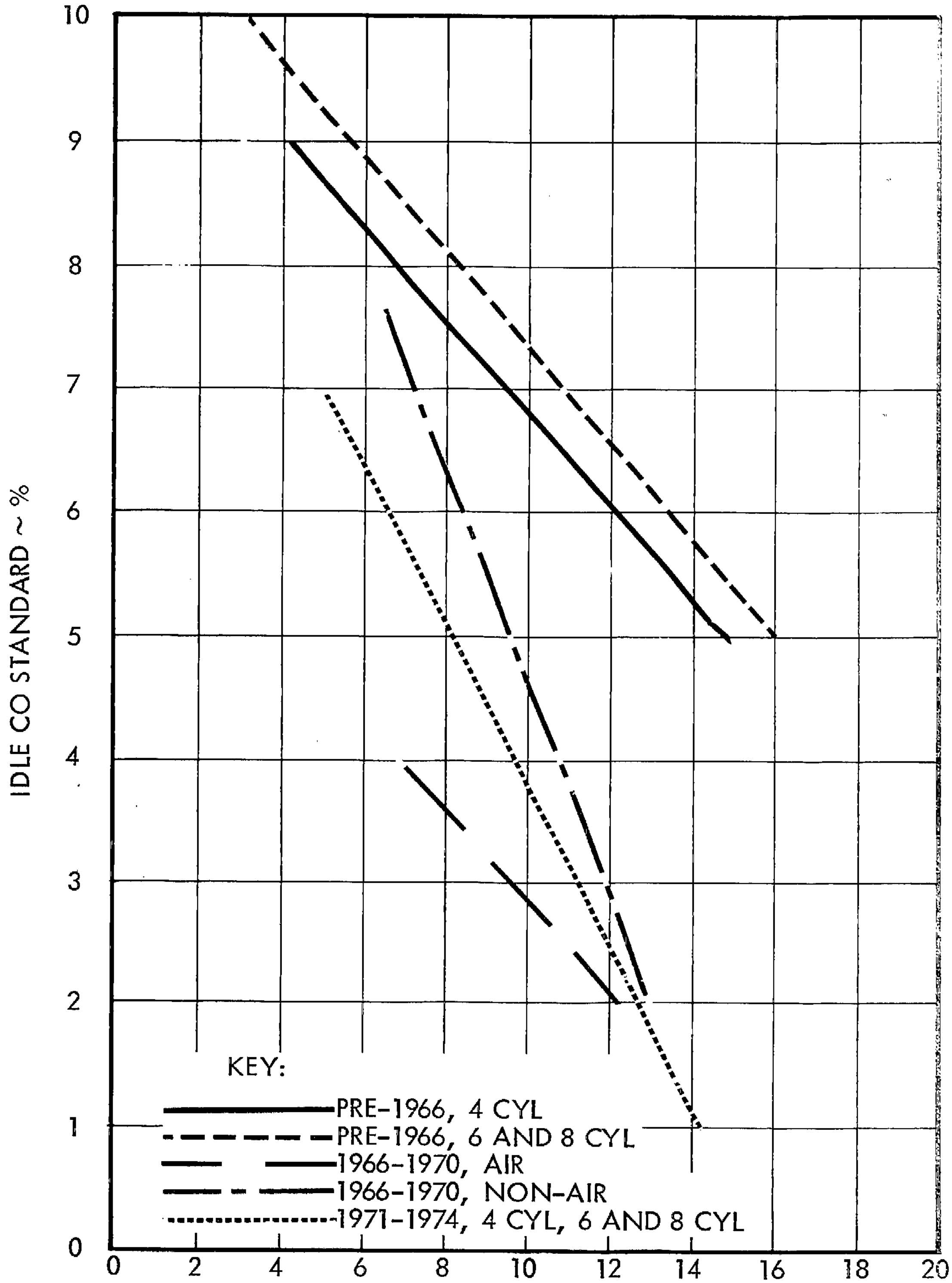

Figure 4-12. Relationship Between Idle CO Standard and CO emission reduction

TABLE 4-21

RECOMMENDED IDLE CO RE-TEST STANDARDS AND THEIR IMPACT ON VEHICLE EMISSIONS

CONTROL TYPE	IDLE CO STANDARD FOR INITIAL INSPECTION	RECOMMENDED IDLE CO RE-TEST STANDARD	EMISSION CHANGES DUE TO MAINTENANCE FOR MEETING RE-TEST STANDARD (TONS/DAY)			
			CO	HC	NOx	WEIGHTED TOTAL REDUCTION
Pre-1966, 4 cylinder	9.00	7.00	+ 3.25	+ .355	+ .169	
Pre-1966, 6 & 8 cylinder	10.0	7.50	+42.3	+4.64	+2.21	
1966-1970, AIR	4.00	3.00	+25.1	+ .165	+0.00	
1966-1970, NON-AIR	7.75	4.50	+131	+ .862	+0.00	
1971-1974, 4 cylinder	7.00	4.00	+155	+1.58	- .806	
1971-1974, 6 & 8 cylinder	7.00	4.00	+449	+4.60	-2.34	
	TOTAL EMISSION CHANGES (TONS/DAY)		+806	+12.2	-0.767	+88.0
	EMISSION CHANGES AS PERCENTS OF TOTAL VEHICLE EMISSIONS		+ 9.3%	+1.79%	- .112%	2.00%

will maximize the benefits of the idle CO re-test, while minimizing the cost in terms of vehicle owner inconvenience and dissatisfaction*.

It is recommended, however, that the inspection program be used to gather data on and evaluate the actual effectiveness of these re-test standards and procedures. Furthermore, consideration should be given to establishing repair procedures that are designed to adjust idle CO to manufactures specification instead of only to the emission standards. This approach would eliminate the need for distinct re-test standards. In any event, the application of different re-test standards for idle CO must be viewed in the context of system efficiency and public acceptance.

4.7 FORECASTED IMPACTS OF EMISSION STANDARDS

TRW's Economic Effectiveness Computer Model [6], along with the experimental emission data base, was used to assess the long term impact of the developed standards on program performance. Forecasts were prepared for the 1974-1978 period. The end point coincides with the limits of reasonable certainty concerning the distribution of power plants to be manufactured through 1978.

The specific case simulated over this time frame consisted of the following elements:

- Measurement of idle, low cruise and high cruise HC, CO, and NOx for the entire South Coast vehicle population.
- Identification of specific engine maladjustments and malfunction through an interpretation of modal signatures using established key mode emission standards.

*Additional data used in estimating the relationship between idle CO and total emission reductions can be found in Appendix E.

- Repair of vehicles with identified maladjustments and malfunctions. The particular engine parameters include: idle air/fuel ratio, idle rpm, timing, misfire, PCV valve, air cleaner, air pump, NOx control and choke system.

This process (measurement,identification and repair) was simulated on an annual bases over the four year period. The model also considers the impact of engine deterioration, owner tampering and unreliable repair on overall program performance. Thus it is designed to provide "real" world estimates on the expected cost-effectiveness of the proposed key mode emission standards.

Some typical quantitative results obtained from the simulations are presented in Figures 4-13 and 4-14 . Figure 4-13 shows a set of forecasted emission time curves for the HC, CO (Panel A) (Panel B) and NOx (Panel C) through 1978. Two opposite effects are shaping these profiles - emission increases due to engine deterioration and emission decreases due to corrective maintenance and the introduction of new vehicles with lower emission levels. A baseline curve (assuming no inspection/maintenance program) is also shown for comparative purposes. These results clearly indicate that the key mode inspection program can help in reducing emission levels from the vehicle population.

Figure 4-14 presents a forecast of vehicle rejection fraction by age category assuming the use of the same standards over the simulated interval. The standards developed for 1971-1974 cars also was applied to the post-1974 vehicles*. The key observation obtained from this graph is the gradual

*The model presently assumes that emission levels for post-1974 vehicles can be characterized in terms of 1971-1974 vehicles (lack of data precludes direct characterization). For relative comparisons, the impact of this assumption will be slight.

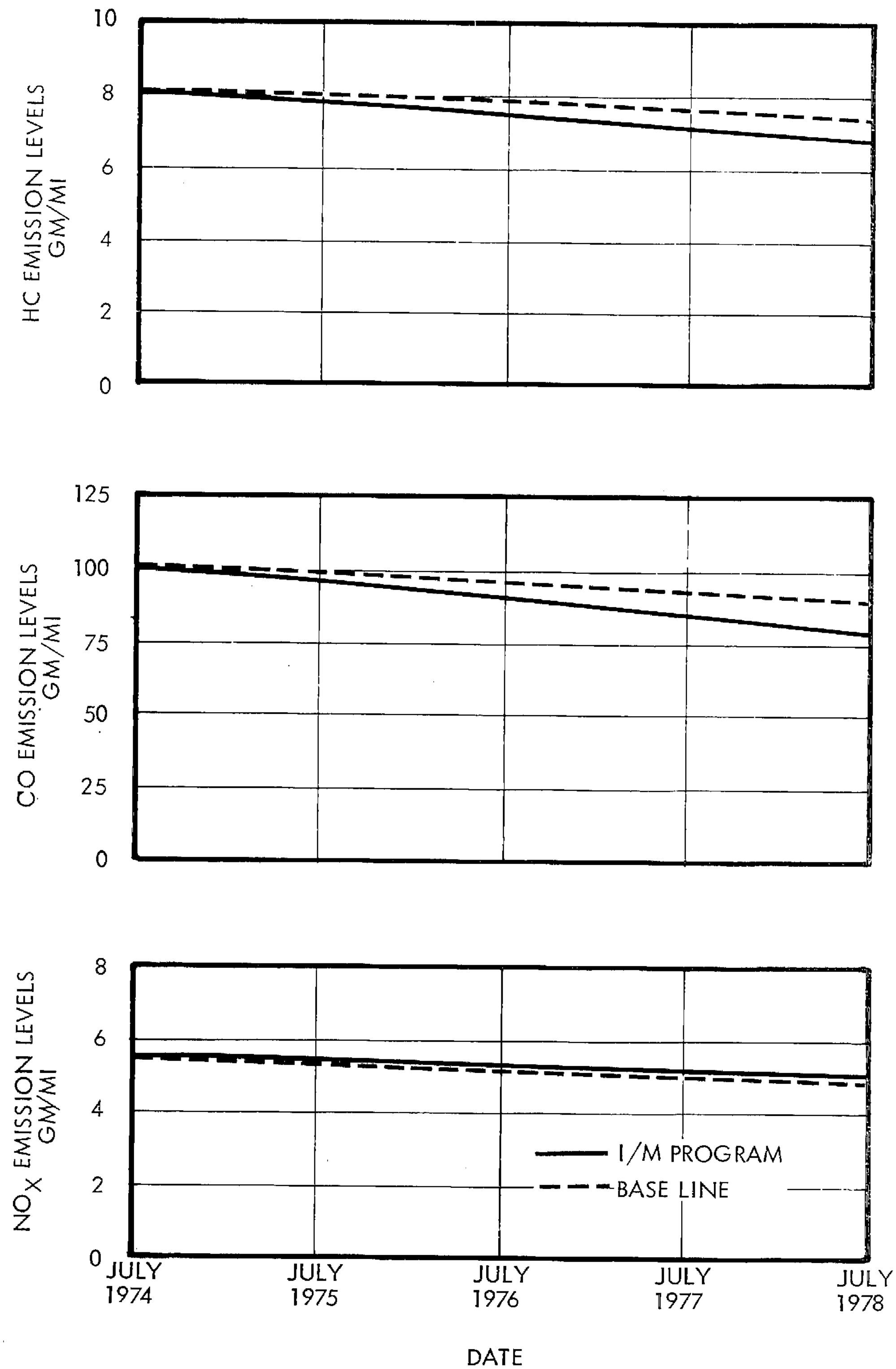

Figure 4-13. Forecasted Emission Levels by Vehicle Class Through 1978

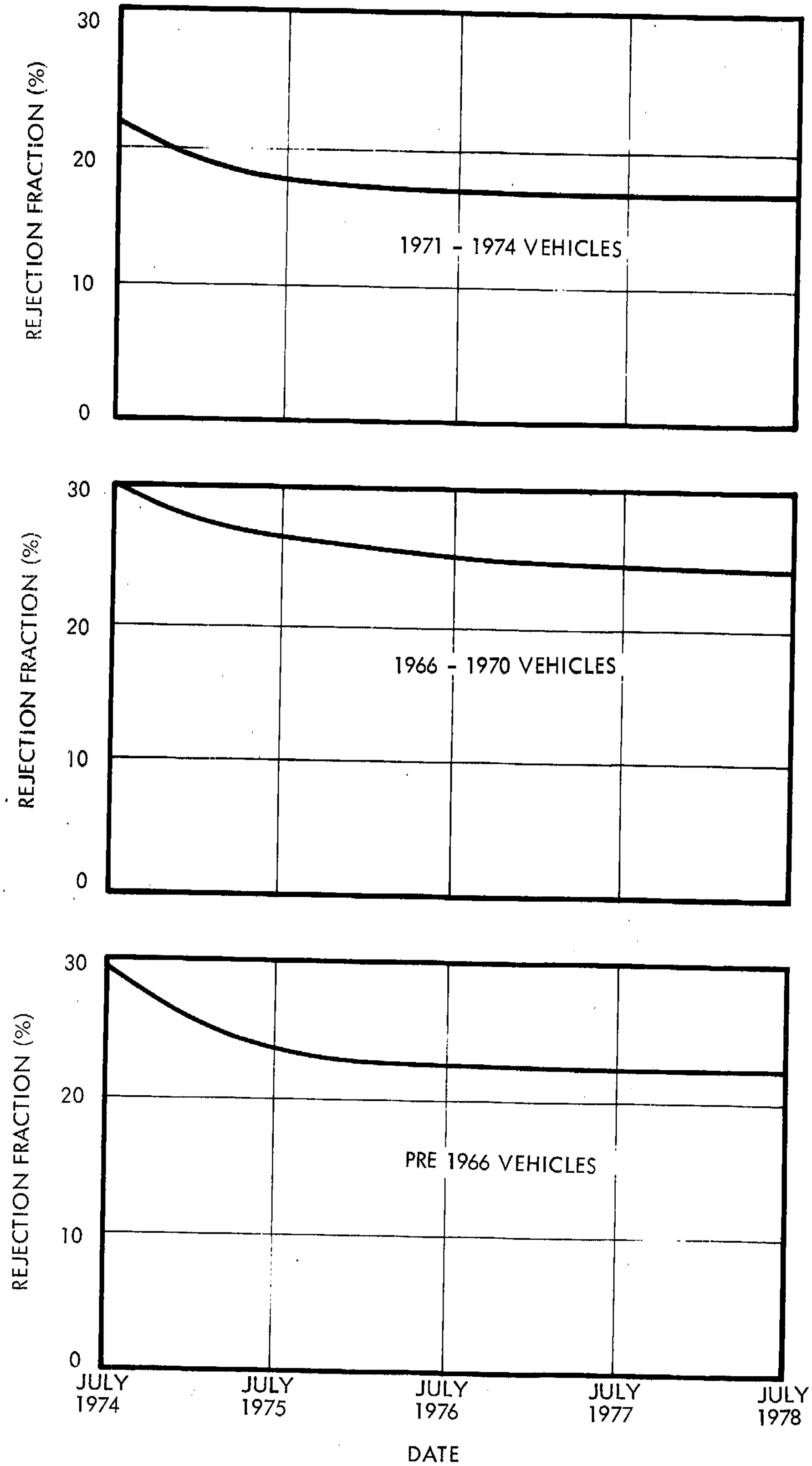

Figure 4-14. Forecasted Rejection Levels by Vehicle Class Through 1978

reduction and the stabilization of the rejection fraction as a function of time. These trends can be attributed to ability of the inspection program to identify and maintain malfunctioning vehicles operating within the vehicle population.

These forecasts show that it might be necessary to upgrade the emission standards periodically in order to achieve a consistant level of emission reduction from the vehicle population. A revised set of emission standards can be developed using the methodology outlined in this report.

4.8 PROGRAM COST ANALYSIS

The following discussion outlines in detail the cost analysis procedure used to develop the basic program cost schedules for the cost-effectiveness calculations shown in Section 4.2. It also presents estimates of the social costs involved in the various inspection programs and evaluates their impact on the selection of cost-effective rejection fractions.

Explicit Program Cost

The explicit costs (i.e., the capital, operating and maintenance costs) of an inspection program can be divided into two components, namely, fixed costs and variable costs. Fixed costs include the cost of inspection facilities, equipment, land, and inspection operating expenses. They are constant and typically are only indirectly a function of rejection level.* Variable costs, on the other hand, are directly

* A rejection rate determines the number of vehicles which will undergo emission re-test and consequently must be factored into designing the capacity of the inspection system. The estimate of $4.00 per vehicle accounts for this additional cost.

dependent on rejection rate, consisting mainly of the costs of the parts and labor necessary to repair vehicles which have failed inspection.

Two kinds of fixed costs were considered in the analysis. The first was the cost of inspection facilities. This included building construction costs, test equipment costs, and land purchase costs. On a region wide basis these costs were estimated to total roughly ten million dollars. This second cost considered was the inspection cost, that is, the actual cost of performing a vehicle inspection. This was estimated to be approximately two dollars per vehicle, or ten million dollars altogether.** Thus, total fixed program costs were put at twenty million dollars or four dollars per vehicle (see Table 4-22).

Variable costs were calculated using the following equation:

$$VC_{ir} = TVPOP \cdot FPOP_i \cdot ARC_j \cdot R$$

where:

VC_{ir} is the total variable cost for classification group i ($i = 1,\ldots n$) at rejection fraction R

TVPOP is the total number of vehicles in the population, five million

$FPOP_i$ is that fraction of the vehicle population found in classification group i

ARC_{ir} is the average repair cost for vehicles which fail inspection in classification group i at rejection fraction R

R is the rejection fraction

The values for FPOP are shown in Table 4-17.

The average repair cost, ARC was estimated as follows:

For a particular rejection fraction R, all group i vehicles in TRW's/CAPE-13 Data Base failing inspection were examined to determine which engine parameters required repair. The cost of repairing each vehicle was then calculated using the cost schedule

** These estimates assume a state financed and operated inspection system. Conducting the program under a franchised system (private industry) would tend to increase the inspection costs.

shown in Table 4-23. By totaling all vehicle repair costs and dividing by the number of vehicles undergoing repair, the average repair cost was obtained. This is shown for each classification group in Table 4-24.

One interesting note regarding these estimates is the general decrease in average repair costs for larger values of R. This can be attributed to the fact that for larger rejection rates the extent of maintenance required, on the average, is less (the additional vehicles identified by larger rejection rates tend to have fewer maladjustments and malfunctions).

The explicit program costs for each classification were then determined by summing the fixed and variable costs as follows:

$$EPC_{ir} = FC \cdot TVPOP \cdot FPOP_i + VC_{ir}$$

where:

EPC_{ir} is the explicit program cost for classification group i at rejection fraction R

FC is the basic fixed cost per vehicle, $4.00

TVPOP, $FPOP_i$, and VC_{ir} are defined as before.

The actual explicit program costs calculated are summarized in Table 4-25 for selected rejection fractions.

Implicit Program Costs

The implicit or social costs associated with a particular inspection program were estimated by determining the opportunity cost of the time spent by the vehicle operators involved in the inspection/maintenance process. Since, it is anticipated that the inspection program will be conducted during working hours, the opportunity cost of the time involved is the value of foregoing wages. This value was placed at $2.00 per hour, the minimum wage in California. Thus, since many people make considerably more than $2.00 an hour, the estimates of social cost should be somewhat conservative.

TABLE 4-22

SUMMARY OF PROGRAM COST ESTIMATES

INVESTMENTS	
Land Acquisition (50 stations x 50K/station)*	$ 2,500,000
Facility Design and Construction (50 stations x 75K/station)	$ 3,750,000
Equipment (50 stations x 70K/station)	$ 3,500,000
Training and Certification	$ 250,000
TOTAL INVESTMENT	$10,000,000**
OPERATIONS AND MAINTENANCE	
Personnel Cost (840 employs x 10K/employ)	$ 8,400,000
Training	$ 100,000
Equipment/Facility Maintenance, Insurance and Misc.	$ 125,000
Computer Operations (@ 25¢ per test)	$ 1,375,000
TOTAL OPERATIONS AND MAINTENANCE	$10,000,000
ANNUAL OPERATING COSTS	
Total	$20,000,000
Total Per Registered Vehicle (@5.0 million)	$4.00/car

* Assumes four lanes per station at 25,000 cars per lane/year

** Due to the uncertain nature of the program financing, capitalization costs were assummed to be incurred over a period of one year.

TABLE 4-23

ENGINE PARAMETER REPAIR COST SCHEDULE

ENGINE PARAMETER	REPAIR COST ($)
Air Pump	65.00
Idle CO Adjustment	1.30 -
Spark Line	7.80
Ignition Point Dwell	2.00
Basic Ignition Timing	2.60
Total Advance at 2500 RPM	3.90
Idle Speed (RPM)	1.30 -
Air Cleaner Angle	7.80
Float Level	3.90
Choke, Vacuum Kick	3.90
Diaphragm	4.50
Heat Riser Valve	2.80
NOx Control Device	36.40
Timing Retard Mechanism	4.00
Misfire Ignition	35.10
PCV Flow	3.90
Air Cleaner Restriction	7.80

• Includes overcharge variance but not basic fixed cost.

TABLE 4-24

AVERAGE REPAIR COSTS BY AGE CLASSIFICATION

REJECTION FRACTION (%)	PRE-1966 VEHICLES ($)	1966-1970 VEHICLES ($)	1971-1974 VEHICLES ($)
10	27.51	33.72	40.98
20	24.94	31.29	40.50
30	24.72	28.04	38.62
40	23.47	27.52	37.97
50	23.28	28.16	38.40

TABLE 4-25

EXPLICIT PROGRAM COST ESTIMATES

REJECTION FRACTION (%)	PRE-1966 VEHICLES ($m)	1966-1970 VEHICLES ($m)	1971-1974 VEHICLES ($m)	TOTAL ($m)
10	6.51	14.7	16.5	37.7
20	8.58	20.3	25.0	53.9
30	10.9	24.6	32.2	67.7
40	12.8	29.7	39.6	82.1
50	14.7	35.8	47.8	98.3

Like the explicit costs, social costs can be divided into fixed and variable components. The fixed component consists of the opportunity costs of the time it takes to inspect a vehicle. This time, including the trip to and from the station, was assumed to be one hour so that the opportunity cost is two dollars per vehicle. The variable part of social costs is the opportunity cost of the time spent by the vehicle operator having his vehicle repaired, also, assumed to be one hours. Thus, the total program cost can be expressed as follows:

$$TPC_{ir} = EPC_{ir} + TPOP \cdot FPOP_i \cdot (FSC + VSC \cdot R)$$

where:

TPC_{ir} is the total program cost for classification group i at rejection fraction R

FSC is the fixed social cost per vehicle, \$2.00

VSC is the variable social cost per vehicles, \$2.00

Table 4-26 through 4-28 presents a comparison of cost-effective results with and without the addition of social costs for each of the five classifications.

These tables also indicate that rejection fraction which is most cost-effective in terms of social cost for each classification group.

A comparison of this data indicates almost no change in the choice of cost-effective rejection fractions using total program cost as opposed to basic program costs. Only in the post-1970 eight cylinder group does a shift occur, from a rejection fraction of 20 percent to 10 percent. Thus, it appears that the rejection fractions selected on the basis of basic program cost are very insensitive to the addition of social cost at the defined rate (i.e., \$2.00/hr). It should be noted, however, that the overall cost-effective results are somewhat

TABLE 4-26

IMPACT OF SOCIAL COSTS ON COST-EFFECTIVENESS RESULTS FOR PRE-1966 VEHICLES

FOUR CYLINDERS

REJECTION FRACTION (%)	EFFECTIVENESS-COST[1] (Tons/Day/$M)	EFFECTIVENESS-COST[2] (Tons/Day/$M)
10	3.41	2.58
20	3.82	3.05
30	2.68	2.28
40	2.72	2.30

SIX AND EIGHT CYLINDERS

REJECTION FRACTION (%)	EFFECTIVENESS-COST (Tons/Day/$M)	EFFECTIVENESS-COST (Tons/Day/$M)
10	1.38	1.05
20	1.42	1.12
30	1.59	1.29
40	1.50	1.23

1. Without Addition of Social Costs
2. With Addition of Social Costs

TABLE 4-27

IMPACT OF SOCIAL COSTS ON COST-EFFECTIVENESS RESULTS FOR 1966-1970 VEHICLES

REJECTION FRACTION (%)	COST EFFECTIVENESS[1] (Tons/Day/$M)	COST-EFFECTIVENESS[2] (Tons/Day/$M)
10	1.72	1.34
20	1.99	1.37
30	2.10	1.34
40	1.91	1.18

1. Without Addition of Social Costs
2. With Addition of Social Costs

TABLE 4-28

IMPACT OF SOCIAL COSTS ON COST-EFFECTIVENESS RESULTS FOR 1971-1974 VEHICLES

FOUR CYLINDERS

REJECTION FRACTION (%)	COST-EFFECTIVENESS[1] (Tons/Day/$M)	COST-EFFECTIVENESS[2] (Tons/Day/$M)
10	0.50	0.378
20	1.78	1.38
30	2.43	1.93
40	1.79	1.45

SIX AND EIGHT CYLINDERS

REJECTION FRACTION (%)	COST-EFFECTIVENESS[1] (Tons/Day/$M)	COST-EFFECTIVENESS[2] (Tons/Day/$M)
10	1.38	1.38
20	1.48	1.25
30	1.22	1.06
40	1.01	0.891

1. Without Addition of Social Costs
2. With Addition of Social Costs

lower with the addition of social costs. This could have an impact on the relative attractiveness of inspection/maintenance vis-a-vis other control alternatives (e.g.,emission retrofit devices).

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APPENDIX A

DATA BASE SUMMARY

APPENDIX A

DATA BASE SUMMARY

This appendix contains a summary of the emissions data used in developing the key mode standards. This data originated from the Cape-13 program. Shown for the three age classifications are key mode (idle, low cruise and high cruise) and CVS mass emissions reductions for 450 vehicles (150 vehicles per age group). The data has been tabulated according to largest to smallest HC emission reduction. That is, the vehicle with the largest HC emission reduction was listed first and so on (each age group is treated separately). These tables provide a systematic overview on the relationship between key mode emission levels (pre-maintenance state) and resultant CVS emission reductions.

DATA BASE SUMMARY

PRE 1966

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	KEY MODES LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
1	69	3869.5	3.57	60.3	2865.8	2.83	493.8	2091.3	1.70	1351.6	27.15	-21.6	.11
2	40	7681.9	6.04	138.4	2040.1	6.00	495.3	1623.7	3.28	2378.1	22.16	-2.8	1.75
3	144	4250.6	2.64	75.7	4374.4	1.48	1163.2	4713.3	2.83	592.0	21.70	-58.2	1.22
4	22	1162.7	9.76	43.0	2054.5	13.44	0.0	1074.5	13.44	0.0	20.61	124.5	-1.15
5	139	1767.0	11.59	24.1	1299.8	12.16	0.0	971.5	12.16	0.0	19.31	74.6	.16
6	26	1180.9	9.96	31.9	780.8	4.08	1372.6	402.0	1.38	1705.1	14.04	102.5	-.54
7	95	2384.1	6.63	23.4	2200.0	2.74	1203.1	1985.7	1.86	2214.1	10.16	-35.5	-1.37
8	136	1415.1	10.25	38.8	485.1	5.00	573.9	316.9	3.07	1366.9	7.67	19.9	.22
9	44	648.0	1.77	12.0	513.8	3.71	1018.4	361.8	2.62	1873.7	7.65	43.4	2.20
10	148	123.5	.33	137.9	139.3	2.25	440.0	142.2	9.22	35.2	7.57	296.3	-2.60
11	94	1674.7	4.46	32.1	613.0	2.93	1049.7	427.9	3.18	1553.0	6.21	1.9	-1.41
12	45	846.0	9.09	50.1	825.8	5.29	513.4	448.4	3.89	1134.2	6.13	73.9	-.47
13	59	587.3	6.07	67.5	425.2	.35	1203.6	305.4	2.94	1755.1	5.61	25.1	1.81
14	106	857.3	11.76	29.8	280.4	5.09	135.4	194.7	5.53	263.7	5.32	111.5	-.80
15	80	569.7	7.72	64.6	499.5	4.17	557.2	374.9	6.23	458.5	5.27	36.4	.68
16	41	1425.1	6.06	40.7	604.2	2.97	761.6	509.6	1.88	1914.7	5.22	37.3	.23
17	135	719.9	2.81	56.0	433.6	.39	1408.2	393.9	1.99	1674.2	5.17	62.4	-.65
18	105	232.7	2.63	47.4	244.2	5.08	170.6	309.2	8.84	83.1	5.05	123.6	-.70
19	24	2043.0	10.34	35.2	1170.4	6.10	402.5	551.4	4.56	894.2	4.75	2.3	.77
20	58	1242.7	7.73	31.2	483.7	2.09	1217.4	327.2	1.85	2295.7	4.62	15.0	-2.71
21	9	2135.7	8.23	116.7	538.9	4.33	703.4	360.2	4.60	1048.9	4.59	25.1	-.52
22	65	479.2	6.83	53.6	421.9	5.68	454.6	225.4	1.64	2578.8	3.52	87.7	-4.71
23	120	1733.3	8.84	56.6	738.4	4.88	734.9	491.4	3.51	1469.1	3.41	13.5	-.31
24	37	419.1	7.12	49.8	449.5	1.84	1832.5	305.2	2.93	1650.2	3.26	42.2	-.40
25	99	328.5	7.58	47.2	260.3	5.31	230.5	168.0	1.92	1581.7	3.21	52.7	-.02
26	141	1159.6	8.63	43.6	1259.5	10.21	97.7	884.6	11.41	44.6	3.21	28.1	2.75
27	21	714.6	10.67	30.0	398.1	2.67	1107.0	315.9	2.45	1673.6	3.06	41.4	.31
28	143	1259.4	8.73	34.6	383.9	2.80	1652.5	246.8	.97	3277.9	2.88	20.5	-.42
29	110	1161.7	11.49	41.2	456.5	2.03	2050.8	323.3	2.29	2969.9	2.85	14.6	.15
30	53	823.8	9.91	21.0	420.0	.93	2931.2	255.9	.92	2889.0	2.81	30.9	.03

DATA BASE SUMMARY

PRE 1966

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	KEY MODES LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
31	100	406.5	8.23	102.0	299.9	1.90	914.6	292.8	3.22	1215.9	2.77	5.2	.37
32	115	355.4	9.51	30.0	298.6	1.33	1557.3	219.5	.64	2587.5	2.75	64.9	-1.52
33	31	457.7	4.72	36.2	344.0	2.93	1476.6	292.3	4.07	1405.3	2.73	27.8	.70
34	137	4426.8	9.05	114.9	555.3	6.64	100.4	412.8	4.11	626.9	2.69	18.2	-.32
35	96	908.4	10.00	29.3	443.8	6.18	685.8	295.3	4.11	1445.4	2.68	45.1	-.18
36	125	411.8	6.45	61.5	301.2	1.62	1099.5	181.9	1.65	1110.5	2.58	73.9	-1.56
37	46	1607.2	9.86	49.4	1031.9	5.60	783.0	522.1	3.65	1677.8	2.66	47.9	.78
38	47	456.9	3.77	11.0	579.8	3.59	771.4	429.5	3.12	1839.6	2.53	27.7	.59
39	84	653.2	11.94	29.1	426.8	5.14	686.5	278.5	2.50	1941.6	2.41	15.0	.08
40	122	501.6	6.31	59.1	345.1	2.86	1016.6	267.7	3.21	1377.2	2.41	18.0	-.43
41	132	895.0	4.40	154.3	553.1	1.35	2696.4	436.2	2.09	2047.6	2.35	7.9	-.16
42	146	297.0	1.53	78.8	413.0	6.32	519.2	252.5	4.84	1210.6	2.29	9.1	1.47
43	25	679.9	12.07	20.9	344.3	1.95	824.6	319.9	4.84	690.1	2.27	19.4	-1.82
44	149	401.1	7.26	43.2	316.9	2.24	1683.6	213.6	1.19	2658.2	2.26	47.5	-2.17
45	39	418.1	5.62	11.7	320.2	3.67	703.0	217.5	3.66	1254.7	2.16	16.7	-1.05
46	150	532.6	5.92	81.8	1581.5	2.95	1257.1	797.4	1.92	2212.6	2.13	23.0	0.00
47	60	0.0	2.44	73.3	350.5	2.53	1259.6	280.5	2.97	1913.7	2.05	-4.4	2.66
48	134	676.5	7.16	46.5	366.8	3.87	978.5	236.3	2.28	1823.8	2.01	31.9	-.35
49	145	267.3	2.23	207.2	186.4	1.09	1605.7	113.9	.35	1997.8	2.01	19.8	.33
50	129	442.1	5.55	46.6	426.8	5.85	174.6	391.8	9.77	81.2	1.98	21.2	.10
51	15	760.1	8.08	38.7	381.5	1.80	2381.9	267.4	1.32	3106.1	1.74	.2	.44
52	121	520.9	6.47	41.3	444.2	2.75	1065.7	343.0	1.17	2457.7	1.61	10.4	-.13
53	74	425.4	2.61	36.9	409.4	2.79	1286.6	323.0	2.76	1858.3	1.59	-16.4	.30
54	27	828.9	7.67	34.5	573.3	4.36	883.2	426.5	5.59	776.8	1.50	.4	-.30
55	53	498.6	6.42	16.2	363.8	6.45	223.7	230.0	1.67	2920.3	1.48	2.3	-.45
56	147	900.9	8.36	20.8	479.0	3.56	1125.0	314.5	2.74	1635.6	1.41	1.2	.37
57	16	510.0	8.30	36.7	487.2	1.14	1913.7	302.8	.65	2848.2	1.31	6.8	-.43
58	117	739.9	8.98	31.7	595.0	2.42	1571.6	385.7	2.35	2967.2	1.21	16.4	-1.33
59	54	721.5	7.29	36.6	414.5	4.51	919.0	291.6	3.97	1383.7	1.16	-.2	.33
60	35	2017.9	6.67	41.5	757.9	8.13	93.1	422.0	2.40	2175.0	1.09	9.6	-.38

DATA BASE SUMMARY

PRE 1966

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	KEY MODES LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
61	34	257.9	1.14	61.4	377.3	4.88	786.0	281.5	5.03	1015.6	1.03	13.0	-.23
62	23	453.3	6.92	55.1	475.8	1.35	1664.7	349.7	2.77	1851.6	.95	19.4	-.23
63	102	342.9	2.27	123.8	428.5	2.70	796.3	311.3	2.87	1250.8	.95	-19.4	.46
64	86	238.9	1.92	20.8	277.3	.46	971.4	210.7	1.35	1427.8	.90	25.1	-1.52
65	66	637.9	6.52	75.4	402.8	2.71	1339.8	271.6	1.66	2560.1	.87	18.2	-1.24
66	13	692.6	5.50	59.9	587.4	5.12	602.0	452.5	4.48	1057.1	.87	10.4	.53
67	133	761.1	6.69	34.8	392.1	2.49	2119.9	266.6	2.26	2219.0	.87	19.7	.51
68	6	719.2	10.49	45.0	369.7	2.81	873.1	287.2	3.03	1241.2	.84	-44.0	.23
69	50	385.5	3.31	66.4	259.0	.85	2068.6	204.4	1.39	3181.2	.83	7.9	1.62
70	127	873.9	1.33	38.1	493.9	3.62	1969.8	340.6	2.20	2170.8	.76	4.9	1.05
71	93	276.1	1.59	57.5	284.7	.64	1028.2	236.1	2.11	1482.8	.74	11.7	-2.35
72	131	748.7	9.92	25.5	539.6	5.19	279.7	362.6	4.31	805.7	.73	22.0	-.08
73	88	487.7	7.35	36.9	314.9	.43	2410.8	254.3	3.02	1567.8	.60	-30.9	1.13
74	73	331.4	7.06	86.6	375.3	3.56	777.4	269.1	2.56	1316.1	.53	-5.4	.12
75	19	676.5	6.56	112.1	412.2	2.61	1503.6	302.8	2.15	2060.1	.46	24.2	-2.20
76	1	529.9	7.82	63.3	372.1	2.44	2097.2	192.7	2.03	2488.5	.46	1.3	-1.38
77	83	1295.8	9.21	31.2	551.7	2.10	631.0	367.7	.62	2072.5	.42	-9.1	-.54
78	5	396.8	4.39	95.3	176.0	2.01	2051.5	137.8	2.27	2522.7	.42	2.2	1.71
79	98	965.5	12.56	43.9	515.3	2.39	1806.6	354.5	4.84	682.2	.40	18.9	-1.98
80	33	354.4	2.63	82.4	351.7	2.36	1480.6	272.5	3.60	1451.1	.39	-4.0	.09
81	82	577.5	3.56	53.5	498.9	3.66	911.5	310.6	2.77	1845.1	.39	-2.7	-.16
82	101	95.9	.12	322.9	90.3	.32	960.9	158.0	1.66	1577.1	.37	28.8	-1.91
83	39	293.0	1.95	5.9	317.3	.94	1250.0	240.3	3.67	630.6	.29	19.7	-.79
84	138	2160.7	5.47	100.1	1338.1	10.27	3.2	897.7	9.31	32.4	.23	1.8	.65
85	62	699.5	6.24	59.2	556.3	6.11	288.2	441.7	6.65	339.3	.18	4.0	.03
86	32	559.1	.94	100.2	471.4	2.57	1426.5	330.1	1.07	3504.9	.07	-.3	1.47
87	61	475.5	5.45	23.4	403.1	6.91	170.5	271.4	7.65	120.0	.07	23.1	-.44
88	78	211.5	3.55	18.3	130.8	.13	1449.7	243.8	8.05	75.6	.05	8.7	-.38
89	126	1340.9	9.39	27.7	602.5	4.21	1913.1	420.4	3.46	2450.8	.02	-24.5	.64
90	20	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.00	0.0	0.00

DATA BASE SUMMARY

PRE 1966

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	KEY MODES LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
91	112	0.0	0.00	0.0	0.0	0.00	0.0	0.0	0.00	0.0	0.00	0.0	0.00
92	107	306.4	7.17	58.1	306.4	4.68	792.1	196.2	3.72	1545.4	-.08	-15.9	.47
93	140	494.1	7.73	33.6	305.7	1.31	1936.8	295.6	5.36	749.8	-.09	4.1	.47
94	70	773.5	9.73	76.9	502.6	3.78	1073.0	294.3	.99	2435.7	-.13	10.9	-.92
95	14	964.6	8.26	128.5	440.4	2.21	1696.7	316.7	6.29	502.0	-.20	20.0	-1.84
96	92	135.4	2.02	187.2	161.2	5.70	100.1	202.9	10.81	31.9	-.27	.9	1.47
97	55	587.5	3.14	102.0	353.9	1.89	1988.9	284.0	2.72	2282.6	-.32	-10.2	-.43
98	7	1764.1	7.84	49.4	937.0	5.60	838.9	506.2	2.34	2260.7	-.33	2.3	-.36
99	18	270.2	1.29	588.7	255.6	3.85	942.7	205.4	4.02	1335.1	-.34	-12.1	-.04
100	43	607.1	7.17	5.0	454.8	1.86	1117.0	294.6	1.55	1883.9	-.38	-17.8	.57
101	108	687.1	7.91	11.5	467.1	5.89	273.6	322.3	4.78	774.2	-.44	18.8	-.17
102	90	82.0	.68	0.0	118.0	.20	461.4	237.5	1.62	2018.8	-.45	-5.1	1.96
103	51	141.7	1.46	18.7	144.4	1.16	856.9	144.4	1.58	1355.5	-.49	-5.1	-.26
104	36	427.6	3.13	54.5	275.7	1.06	881.1	220.6	.89	1490.5	-.50	7.6	-.89
105	79	795.2	6.51	24.1	455.3	4.34	409.7	368.0	6.11	518.5	-.62	-40.1	.29
106	97	344.3	4.59	70.2	283.8	2.11	847.7	238.2	2.88	1086.5	-.68	-69.3	.24
107	91	363.4	4.47	33.4	269.3	2.06	579.8	165.7	.80	1687.1	-.68	11.4	-1.68
108	142	659.3	6.42	41.2	635.5	2.91	942.4	455.9	1.87	2221.4	-.71	-13.4	.03
109	77	431.5	3.42	96.0	318.3	2.05	593.4	227.3	.47	2015.3	-.79	14.0	-3.03
110	71	524.1	6.58	63.6	236.8	.14	1694.2	191.9	.34	2930.5	-.85	10.2	-.34
111	76	288.1	4.46	102.2	231.9	.20	2879.4	183.3	.15	3482.2	-.85	3.6	-.23
112	111	636.4	6.05	329.6	329.1	.74	3213.8	288.5	2.46	2743.6	-.87	-45.5	5.57
113	114	527.6	9.81	49.8	290.2	.99	1600.8	204.9	1.38	1770.5	-.99	6.3	-1.19
114	130	341.7	3.79	194.0	257.9	1.51	891.7	364.4	9.99	43.3	-.99	79.4	-2.20
115	52	581.1	7.44	8.9	342.0	1.72	1393.2	378.4	8.45	169.0	-.99	-17.0	-.33
116	85	458.3	6.85	38.8	403.2	1.39	2426.5	289.1	.72	3386.4	-1.04	-9.3	-.23
117	10	404.1	5.87	63.6	269.8	1.59	992.1	198.6	1.52	1656.7	-1.11	7.3	-2.29
118	104	648.1	5.83	46.4	460.8	3.99	1186.0	258.1	1.38	2545.1	-1.34	-12.7	-.10
119	12	793.5	11.32	26.4	480.1	3.21	864.7	346.3	5.35	503.3	-1.42	10.0	-.86
120	118	4143.2	6.81	46.3	491.8	2.29	2095.9	333.8	1.43	2557.3	-1.50	-24.3	.71

DATA BASE SUMMARY

PRE 1966

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
121	11	330.8	1.58	268.1	288.8	2.45	1373.2	256.7	3.30	1496.4	-1.62	-26.0	.88
122	30	396.7	.17	871.7	415.7	5.05	572.5	314.1	3.05	1587.3	-1.71	-18.1	.58
123	67	398.8	4.69	75.0	351.7	3.99	932.5	222.8	2.02	2343.7	-1.76	-17.2	-1.33
124	57	285.8	5.10	61.1	200.4	1.37	726.2	126.0	.99	1490.1	-1.91	-9.6	-1.17
125	128	280.8	2.51	45.7	337.6	7.46	194.1	288.3	11.51	0.0	-1.94	-32.9	.63
126	29	193.6	.73	41.7	231.9	.90	2288.0	171.9	.72	3324.3	-2.01	-26.2	-1.50
127	48	345.6	5.20	29.6	363.9	4.29	206.4	320.2	4.61	571.9	-2.06	15.9	1.52
128	38	457.2	5.14	41.0	234.0	1.39	572.0	223.1	1.06	1477.2	-2.11	30.6	-2.81
129	119	1635.8	5.43	41.2	817.2	5.59	348.2	541.9	3.84	1007.2	-2.12	-14.4	-.35
130	56	228.5	3.20	9.8	282.2	1.15	1788.7	212.1	.76	3269.5	-2.16	-28.6	-3.06
131	28	839.2	9.22	34.3	553.9	3.95	776.8	387.7	3.95	1256.3	-2.21	-11.2	-1.62
132	4	243.0	3.90	45.6	118.9	.21	1362.4	115.0	1.08	2077.6	-2.22	-23.1	-4.63
133	72	324.5	2.37	290.4	240.7	.25	2529.6	251.9	2.51	1845.4	-2.30	-24.5	-.83
134	8	631.6	4.28	162.5	200.7	1.91	1179.0	221.8	4.16	1258.6	-2.45	-94.2	2.39
135	81	287.1	.40	356.4	176.6	.77	1301.9	212.7	4.24	944.9	-2.56	-29.4	-.41
136	58	1629.7	8.14	32.1	633.3	2.31	1817.8	454.7	2.89	2219.5	-2.85	-29.1	.11
137	64	600.7	3.99	31.8	639.6	6.60	115.6	383.3	3.91	525.8	-2.93	-13.0	-.39
138	124	560.8	7.21	44.3	484.7	2.64	1230.3	305.7	2.33	1814.9	-3.42	-28.0	-.37
139	109	4714.3	8.55	119.5	1256.2	13.36	0.0	821.6	8.94	218.5	-3.64	7.6	.39
140	116	556.1	7.73	27.2	344.2	3.31	646.3	357.4	6.76	273.7	-3.69	3.8	-.25
141	87	571.4	8.69	20.9	472.2	4.55	502.3	330.6	4.11	954.2	-4.09	-24.7	.59
142	103	198.7	3.67	16.6	207.2	3.83	421.1	178.9	3.18	983.5	-4.13	-13.3	-.44
143	75	556.6	5.23	22.6	359.2	1.29	1386.6	241.8	2.66	1203.2	-5.48	-4.7	1.44
144	49	318.2	4.56	34.6	396.9	4.31	819.1	276.6	3.22	1708.8	-5.76	-64.7	.56
145	17	439.5	8.44	58.6	197.0	1.80	1037.3	202.2	4.39	782.6	-5.99	8.4	-.70
146	2	1215.6	10.03	40.9	435.6	4.62	254.4	247.4	1.73	2028.5	-6.59	-56.8	-.10
147	42	2405.8	11.60	57.4	735.2	6.18	311.6	487.3	3.90	967.3	-6.77	-33.0	.31
148	113	638.6	5.43	39.6	330.0	6.26	237.4	251.0	3.70	973.9	-7.07	-26.5	-3.27
149	3	229.1	2.63	127.0	229.1	1.32	1932.9	187.7	1.65	2440.4	-7.59	-98.2	2.35
150	123	1048.1	6.90	59.4	271.2	3.53	1273.0	125.6	1.57	2864.7	-8.83	11.2	-1.49

DATA BASE SUMMARY

1966-1970

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	KEY MODES LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
1	601	2031.8	8.86	47.8	277.2	3.13	997.6	179.8	.87	2025.4	23.31	62.4	-.64
2	234	852.3	4.77	59.7	243.1	.31	2242.0	209.1	.28	3900.6	20.81	-3.2	-.28
3	262	485.4	4.31	75.7	174.1	.32	2193.1	142.4	.35	4311.6	14.12	-2.6	3.04
4	263	435.8	6.55	38.5	409.6	5.51	463.5	413.9	0.00	187.4	12.07	105.8	-.68
5	197	614.6	1.48	179.7	232.3	.91	2326.6	205.0	1.86	2355.8	8.10	47.7	-1.57
6	227	1094.6	1.46	43.8	158.9	.22	552.9	168.4	.34	2527.1	6.99	-15.7	1.57
7	188	603.8	4.58	87.7	264.2	.21	3381.0	135.0	.17	3747.9	4.86	-42.0	-1.23
8	280	313.6	4.19	78.0	120.2	.17	1086.3	141.2	.22	3065.6	4.03	3.7	1.20
9	169	347.5	3.82	73.5	290.4	3.21	1522.5	243.9	2.35	1855.1	3.48	5.5	.29
10	295	305.8	7.27	64.6	185.1	2.26	2017.1	122.3	.64	3354.8	3.37	-2.7	1.40
11	200	0.0	6.69	43.6	329.3	5.46	353.0	189.3	.41	3758.5	2.93	35.5	5.54
12	164	5041.3	2.07	48.3	230.1	1.85	823.2	162.1	1.59	1375.2	2.86	-29.0	.80
13	160	299.7	5.65	60.3	149.9	.44	1813.8	168.0	1.12	2784.4	2.80	28.6	-.35
14	193	353.3	.33	205.7	272.1	.83	2893.9	218.6	.42	4283.2	2.73	-33.9	1.48
15	199	802.3	2.87	36.3	285.3	3.23	350.2	231.2	1.85	1991.8	2.68	3.9	-.51
16	204	161.0	2.52	59.7	632.8	.40	1888.0	181.0	.41	2176.7	2.54	-37.2	1.15
17	184	400.2	4.41	353.8	317.9	1.71	1629.3	195.0	.39	2794.3	2.50	36.7	.86
18	251	404.1	10.33	26.4	384.8	1.40	1912.1	238.2	.47	2754.2	2.46	11.9	-.60
19	182	334.8	3.12	0.0	169.3	2.16	0.0	129.9	.93	0.0	2.40	36.1	0.00
20	157	230.7	3.65	100.8	255.6	.26	2800.7	252.9	.45	4233.0	2.27	12.0	.21
21	210	557.6	2.01	27.6	314.2	.21	1422.8	206.7	.33	1944.6	2.27	-32.9	2.83
22	282	329.7	2.21	93.7	165.1	.97	757.2	100.7	1.29	1017.3	2.24	-17.4	-1.09
23	291	365.5	2.09	84.3	185.1	.37	2297.9	138.2	.23	3453.7	2.22	13.8	2.13
24	155	381.2	3.03	30.0	138.4	2.41	189.0	133.2	2.40	657.9	2.16	31.5	-.69
25	174	238.0	3.32	62.3	155.0	1.41	371.2	120.2	1.76	596.1	2.14	10.1	-1.79
26	250	1102.8	2.13	40.7	325.0	2.01	1059.1	271.8	1.90	1990.9	2.13	23.0	-.39
27	264	423.4	9.60	24.3	302.0	2.00	1330.2	189.9	.64	3244.0	2.11	35.0	-4.21
28	249	280.4	4.17	64.7	294.5	1.65	1590.1	184.0	.41	2914.1	2.07	20.9	-.63
29	206	121.6	1.72	4.7	125.7	.77	476.1	146.9	1.96	1359.8	1.77	12.7	.50
30	300	328.2	1.13	0.0	65.2	.96	0.0	58.2	.51	0.0	1.77	-59.6	0.00

DATA BASE SUMMARY

1966-1970

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	KEY MODES LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
31	286	122.6	2.86	67.2	189.9	.17	3051.5	113.7	.17	2636.6	1.67	-9.0	.68
32	228	341.5	2.80	21.2	354.8	.89	1272.8	245.8	.16	3093.4	1.59	69.5	-2.56
33	167	647.8	6.23	49.6	409.6	4.80	312.9	230.1	2.67	1088.2	1.59	33.5	-3.75
34	284	330.4	1.95	95.1	196.5	.72	1889.8	145.3	.89	2669.2	1.52	-13.5	.62
35	201	95.2	8.79	51.2	0.0	2.81	384.9	0.0	1.90	1808.4	1.50	29.8	-.15
36	285	218.4	6.50	49.2	183.5	.43	2510.0	170.8	.50	3667.7	1.50	14.8	2.61
37	290	155.2	2.72	19.2	134.6	.36	1146.5	106.8	.65	2158.9	1.48	-2.5	-.43
38	236	344.3	6.16	94.8	179.3	.15	2191.9	126.4	.15	2982.4	1.42	25.1	-.95
39	274	1634.1	7.76	45.2	208.1	1.60	1597.1	186.8	1.48	2591.2	1.42	-5.6	3.30
40	277	246.4	3.43	62.3	179.7	1.50	1116.0	156.2	1.76	2798.6	1.41	-9.1	.03
41	166	449.9	6.92	59.3	240.1	.28	2591.6	193.9	.78	2729.5	1.38	5.9	1.34
42	195	659.5	5.83	14.1	355.3	1.90	765.2	257.7	3.18	1823.2	1.37	17.1	-.27
43	273	248.2	5.63	139.7	280.7	.41	2630.9	185.0	.33	3517.0	1.34	34.4	-1.25
44	202	311.8	1.12	32.5	135.4	.20	1592.4	60.6	.23	2122.2	1.34	29.8	-2.16
45	245	331.7	4.29	4.9	296.2	1.46	1803.5	204.8	.87	2530.4	1.32	-27.5	-2.28
46	289	264.1	.78	59.9	256.4	.45	1978.0	206.4	.33	2938.4	1.31	3.6	-.07
47	153	196.9	.91	13.7	30.0	.81	462.3	17.5	2.26	162.6	1.29	-14.5	-3.02
48	235	267.2	5.14	8.3	238.9	3.85	0.0	245.9	3.90	995.3	1.28	135.1	-1.03
49	271	206.6	5.06	100.9	331.8	1.15	2483.0	243.8	2.02	2335.8	1.25	15.0	-1.36
50	211	259.1	5.54	337.3	307.2	.91	2060.0	271.3	2.51	2109.4	1.21	21.4	2.57
51	194	409.1	5.64	37.3	328.1	1.51	1070.4	282.2	.93	2558.4	1.21	.4	6.45
52	196	148.2	2.53	79.4	164.6	.21	1699.9	85.6	.16	1349.6	1.19	35.3	-3.11
53	154	94.7	1.49	67.4	182.4	1.32	1202.7	135.3	.55	2714.9	1.17	25.1	.74
54	287	231.7	2.95	11.4	214.0	2.46	518.3	184.3	3.58	623.3	1.16	26.3	-.39
55	170	199.0	8.44	69.2	275.9	.48	1801.9	228.1	.20	4171.6	1.16	61.2	-1.23
56	162	239.9	3.78	43.8	202.9	.54	40.9	188.4	1.35	2658.0	1.11	-1.9	-2.09
57	253	520.3	2.11	42.0	171.7	1.40	942.1	151.1	1.79	2851.3	1.00	1.5	.09
58	214	397.4	2.56	9.3	106.5	.43	924.7	60.2	.15	2133.5	.97	24.0	.63
59	297	217.1	4.67	78.5	241.7	.68	1790.0	245.9	1.20	2823.8	.97	8.3	-.68
60	226	133.2	1.61	13.9	145.3	.18	723.8	143.9	.23	2655.8	.96	-6.0	-1.50

DATA BASE SUMMARY

1966-1970

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
					KEY MODES								
61	272	341.1	2.78	56.7	196.7	1.12	1815.3	119.7	.23	2704.1	.96	11.7	-.10
62	238	291.6	1.39	11.0	228.5	1.13	845.8	225.7	1.77	1751.4	.94	21.3	-1.39
63	168	251.1	7.31	32.2	274.1	.82	2050.6	180.1	.59	3808.6	.82	-2.5	-.17
64	256	191.9	2.88	26.7	178.5	.50	1024.5	174.4	2.37	852.2	.80	-25.7	1.12
65	165	313.0	8.10	22.4	807.4	7.56	137.0	556.0	6.13	968.9	.79	11.1	.10
66	181	157.2	2.54	26.3	231.8	1.22	1237.4	165.3	.40	2322.0	.77	-12.3	0.00
67	294	295.9	4.26	69.6	279.4	1.80	1986.0	182.3	1.05	3438.5	.74	16.9	-.13
68	293	273.6	3.19	14.5	125.3	1.85	247.2	142.2	1.61	1922.2	.71	-.4	2.34
69	288	195.0	9.17	49.5	186.6	1.79	910.4	150.1	1.86	1602.7	.66	9.8	.28
70	207	414.0	2.56	23.5	128.3	1.35	732.0	108.2	1.74	1191.3	.57	24.4	-.74
71	246	796.0	8.05	33.7	249.1	1.89	730.2	122.3	1.13	1933.1	.56	17.1	-1.11
72	178	3868.2	2.44	21.8	174.1	2.68	914.9	179.4	3.08	1537.3	.54	-6.0	4.76
73	179	262.2	2.99	82.1	3627.9	1.46	768.6	3591.3	.57	1961.5	.52	9.1	-2.10
74	261	250.8	6.17	61.8	169.0	1.95	2372.7	100.7	.86	3759.3	.51	-42.1	1.71
75	248	298.9	1.15	200.1	274.0	.74	1993.4	211.8	.16	3455.9	.50	-8.4	-.32
76	279	257.4	6.93	34.8	435.5	3.23	1445.3	291.8	1.52	2584.3	.47	-5.9	.30
77	252	193.8	4.35	78.7	298.1	.28	3470.3	238.2	.47	4530.0	.46	36.6	2.87
78	266	106.8	.87	93.3	201.2	.67	1181.0	208.2	.72	3312.9	.46	-38.2	1.90
79	156	286.2	6.60	24.5	247.6	2.09	756.1	165.0	1.57	1591.4	.46	23.0	-2.45
80	205	187.1	3.38	51.6	237.4	1.87	1528.8	174.6	1.05	2811.4	.44	9.6	-1.40
81	231	136.3	6.98	66.5	258.1	.24	1968.9	178.2	1.12	2016.4	.37	-10.5	-2.56
82	247	223.0	.13	21.6	251.4	1.40	1071.6	171.9	.47	2796.2	.37	.3	2.26
83	243	153.8	.73	3.5	203.4	1.62	614.1	184.1	.58	2792.4	.35	-2.6	-.19
84	258	211.9	.34	65.1	137.8	.18	831.7	131.0	.21	2731.5	.27	-24.1	-.04
85	270	229.7	7.57	19.5	245.3	.48	1207.4	214.3	.58	2414.5	.26	-6.0	-2.87
86	233	375.8	1.04	103.2	253.1	.59	2495.3	178.1	.38	3600.4	.24	-8.5	-1.63
87	161	195.0	5.45	60.5	223.8	2.31	720.9	212.0	1.15	2136.7	.15	80.5	-1.51
88	215	231.2	9.26	30.0	302.5	2.68	1755.7	229.8	1.03	3644.6	.15	30.8	-3.51
89	172	284.9	1.91	88.9	224.1	.39	1759.8	141.4	.20	2544.7	.13	27.9	-.59
90	283	170.8	6.36	78.0	300.3	2.03	1010.2	191.1	.98	2398.1	.12	15.1	1.19

DATA BASE SUMMARY

1966-1970

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
91	265	152.2	8.95	36.8	325.9	2.04	1832.9	147.2	.21	3021.8	.11	28.4	1.63
92	268	285.8	3.86	112.4	188.0	.14	1225.3	159.9	.45	1966.9	.11	4.3	.15
93	159	147.3	4.65	7.6	373.5	5.17	311.6	341.8	3.60	1911.6	.02	-11.7	-2.30
94	269	349.4	6.01	66.5	226.2	.88	1885.5	179.8	1.88	1621.9	-.02	6.6	-2.44
95	176	164.0	6.65	90.5	261.6	.15	1471.4	384.9	0.00	158.4	-.06	-22.3	-.44
96	298	199.4	2.03	92.4	201.5	.32	3763.2	149.4	.38	4103.9	-.06	5.1	.09
97	213	193.8	6.06	71.6	177.0	1.00	1626.1	175.7	1.39	2804.4	-.07	9.5	-2.36
98	292	132.4	8.15	43.4	294.4	.57	3000.6	222.8	1.13	3584.1	-.11	18.4	.85
99	198	264.4	2.11	122.4	712.2	3.02	1589.7	631.3	.74	5272.4	-.11	77.6	.15
100	257	59.0	2.71	40.6	152.4	.47	1310.3	145.3	.59	2616.4	-.14	21.1	1.51
101	237	166.6	5.37	66.7	252.9	.13	2587.0	247.4	1.79	2531.7	-.17	5.8	2.08
102	212	240.7	5.36	52.9	267.4	3.29	1102.1	222.0	3.88	1523.2	-.24	7.0	.22
103	175	419.7	4.15	60.1	211.6	1.58	791.7	191.8	1.27	1973.4	-.25	8.9	.67
104	232	160.5	3.46	15.6	147.0	.35	1784.0	147.0	1.14	2382.7	-.25	38.1	-3.04
105	173	182.4	2.10	137.7	297.0	1.19	2238.3	144.3	.29	2330.6	-.30	-8.5	1.30
106	255	178.5	1.06	190.9	258.9	.91	2733.9	158.5	.18	3820.8	-.48	-.9	-2.10
107	190	377.9	3.73	87.0	267.6	1.59	2259.3	217.8	.58	3314.6	-.48	-20.6	.44
108	229	168.7	6.37	53.4	200.8	1.33	2274.0	141.4	.92	4153.2	-.50	16.4	4.05
109	242	131.0	2.94	100.1	269.2	.34	1775.1	254.0	.70	2944.1	-.57	-41.8	-.21
110	222	284.0	.57	49.2	151.5	1.16	822.2	81.1	.79	1397.4	-.58	-15.4	1.02
111	192	164.4	6.48	58.5	271.7	3.66	2083.9	218.3	1.97	2844.7	-.61	-20.9	.75
112	186	84.6	2.77	79.7	204.8	1.69	1744.1	145.6	.50	3324.7	-.62	-12.0	-2.48
113	267	227.5	.60	0.0	112.3	.43	427.1	105.4	.45	1296.9	-.65	7.6	.38
114	220	203.7	2.21	6.4	159.6	1.91	388.4	166.6	2.30	680.8	-.70	-13.7	.05
115	183	292.8	5.78	78.2	327.7	1.67	2338.7	219.2	.39	4169.1	-.75	57.0	-2.14
116	281	149.6	.51	37.2	189.9	.78	2020.3	172.9	2.28	1654.1	-.79	-77.0	1.92
117	278	753.7	.40	164.7	266.4	.11	2720.8	219.2	.14	4119.6	-.79	-2.8	6.95
118	158	794.4	.82	122.6	186.6	.12	3374.8	150.9	.13	4326.3	-.80	18.4	1.63
119	218	124.3	6.71	53.9	293.2	.14	3226.1	225.7	.15	3886.8	-1.06	31.8	-3.71
120	296	298.8	5.46	36.9	262.3	2.58	1532.8	162.1	1.36	2714.5	-1.08	64.9	-4.08

DATA BASE SUMMARY

1966-1970

KEY MODES

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
121	180	133.1	.54	440.2	289.5	.19	3658.2	247.2	.44	3447.2	-1.10	-10.1	7.30
122	219	152.6	2.08	58.2	150.9	.64	1283.8	137.6	1.43	1619.2	-1.12	.0	-.28
123	191	306.3	7.45	15.8	173.0	1.48	1195.6	135.2	1.87	1433.4	-1.14	2.2	-.94
124	177	222.0	.32	179.7	217.2	.78	2715.2	158.7	.61	3584.6	-1.27	-2.3	.15
125	224	177.9	2.61	87.5	208.4	.31	2338.7	139.2	.24	2979.4	-1.28	-7.5	.01
126	216	183.5	4.13	75.1	276.3	2.05	1789.8	206.7	2.06	2123.3	-1.28	-7.4	.44
127	225	130.5	2.68	18.3	241.4	.57	1405.0	190.0	.37	2516.7	-1.30	-7.0	1.08
128	189	273.1	6.33	37.0	292.3	.64	1051.9	257.7	.22	2728.0	-1.35	-.9	1.51
129	217	377.1	.96	230.4	158.2	.77	1223.6	168.9	1.19	2268.0	-1.37	-14.7	-2.65
130	223	197.7	1.97	40.5	329.0	.92	690.1	264.4	.88	2285.4	-1.40	-10.4	-2.67
131	221	132.8	5.32	75.8	254.6	.48	2910.5	185.9	.30	4055.8	-1.50	-8.1	-.93
132	152	54.0	13.49	0.0	1401.7	7.48	0.0	615.1	1.90	0.0	-1.71	97.9	0.00
133	163	179.0	3.39	101.6	225.5	.27	3391.4	171.1	.24	3575.6	-1.80	28.1	-.65
134	276	181.1	1.42	117.6	283.9	.89	1459.5	273.8	.75	3351.2	-1.89	-10.3	-2.67
135	185	185.1	6.64	70.9	335.5	3.44	1056.4	221.0	1.12	2673.3	-1.94	39.4	-1.38
136	209	754.9	7.49	41.4	209.7	.70	1494.4	183.8	.52	2714.5	-2.00	-71.2	1.34
137	241	298.3	9.66	44.5	465.3	6.49	192.6	303.0	3.41	1438.3	-2.03	-9.0	.09
138	230	482.8	4.52	32.2	184.9	.39	2172.7	218.6	1.59	2612.5	-2.06	20.1	-.08
139	203	208.6	1.77	158.5	235.4	.14	2728.0	86.1	.20	1802.0	-2.49	9.3	.52
140	244	227.6	.75	34.1	173.5	.42	1358.9	142.6	.28	2419.6	-2.62	-5.1	.91
141	187	445.6	3.12	20.8	68.6	.96	787.2	68.6	.45	2789.7	-2.88	6.0	-1.22
142	299	126.9	2.66	67.7	219.4	1.19	1746.8	170.8	1.42	2410.4	-2.98	-10.1	.70
143	240	625.7	.65	84.1	185.8	.50	1456.6	177.6	1.10	2362.6	-2.99	-3.9	-1.15
144	254	158.5	3.27	24.4	228.0	.61	1855.9	176.7	.15	3306.0	-3.02	21.7	.39
145	275	253.8	5.05	40.8	1523.0	1.05	1913.7	1373.7	.63	2580.8	-3.12	-11.2	1.80
146	260	249.4	1.32	176.4	309.3	2.94	1063.5	227.3	1.70	2313.7	-3.71	27.6	-4.66
147	239	121.7	4.74	80.4	317.8	3.31	1405.6	265.5	3.48	1661.0	-4.10	28.7	.50
148	208	241.2	4.53	53.3	236.6	1.98	1450.3	171.3	1.57	2395.5	-5.78	-.2	2.93

DATA BASE SUMMARY

1971-1974

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
1	325	317.7	5.56	84.7	281.2	1.96	1880.8	188.2	.68	3077.4	4.92	70.8	6.22
2	439	170.5	4.09	86.1	186.4	1.64	785.8	163.3	1.39	2063.1	3.96	49.7	-1.16
3	339	301.2	2.32	36.0	299.7	1.57	1122.1	271.4	1.33	2671.1	3.82	12.1	.35
4	409	139.1	2.82	62.4	122.6	.94	1367.7	80.0	.31	2308.7	3.48	167.3	-4.61
5	437	228.6	6.93	42.6	91.7	.20	727.0	154.7	.81	2716.3	2.95	21.5	-.45
6	354	230.2	1.16	65.5	209.3	1.61	1608.2	173.3	1.05	2554.8	2.82	36.7	.53
7	442	256.1	4.36	29.8	113.6	.62	1515.3	93.1	.77	2627.2	2.80	34.7	1.03
8	360	485.4	6.63	13.6	189.1	1.02	734.1	207.3	1.47	2182.2	2.78	1.8	1.96
9	337	245.2	2.04	41.7	274.6	.48	1211.0	270.4	1.32	2402.7	2.56	15.2	-.81
10	355	286.2	8.02	34.4	128.1	.17	1966.9	126.7	.92	2815.7	2.46	54.1	-2.69
11	321	209.8	3.51	84.2	139.0	1.55	1305.1	90.0	.52	2620.9	2.45	42.6	3.18
12	441	135.4	.25	48.6	106.3	.22	1035.5	147.1	1.11	2974.7	2.43	9.1	-.74
13	430	406.8	8.27	30.0	211.1	.25	1996.4	185.0	.30	3413.7	2.39	54.2	-.60
14	363	256.8	6.58	49.9	217.5	1.12	1128.9	115.1	.30	1726.1	2.35	12.4	-.11
15	406	123.0	.86	235.6	137.2	.42	1434.6	123.0	.48	2332.0	2.23	8.5	-.92
16	438	466.9	5.87	80.3	198.0	.28	1095.4	241.3	4.74	614.2	2.21	35.7	-2.08
17	311	132.7	.71	224.2	95.6	.24	1521.9	114.7	.32	2883.5	2.06	20.9	1.31
18	401	287.6	3.64	89.7	204.7	.38	1270.3	158.0	.18	2668.5	2.03	-22.2	1.99
19	345	2240.4	3.74	40.8	175.3	2.80	429.2	140.0	2.12	1121.1	1.83	-7.5	-4.45
20	369	299.1	8.15	43.5	379.1	4.77	662.0	377.6	5.57	350.0	1.71	44.4	.01
21	449	217.2	2.92	70.4	157.3	.51	1692.0	147.2	.51	4019.1	1.69	24.3	1.24
22	310	176.4	1.41	145.1	121.0	.36	1736.5	127.4	.52	3320.9	1.68	33.7	3.97
23	428	291.9	7.63	43.5	179.1	.75	1477.6	170.3	.60	2571.9	1.59	18.0	1.64
24	359	223.9	3.30	117.2	176.6	1.00	826.1	213.3	.80	2310.5	1.57	22.0	.94
25	388	308.8	7.22	62.0	261.1	2.90	419.4	213.8	2.33	1312.7	1.55	31.8	-.06
26	434	304.0	7.58	51.1	178.8	.70	692.0	290.7	1.59	1568.3	1.52	38.8	.24
27	446	424.2	5.26	60.6	353.6	2.04	1814.3	197.7	.18	2793.2	1.46	14.1	1.19
28	338	331.6	7.86	28.6	246.6	3.91	541.9	197.7	1.76	2277.4	1.44	23.5	1.24
29	424	134.4	.31	235.1	83.1	.14	1511.8	60.4	.19	2319.1	1.44	3.7	.26
30	416	266.4	6.56	36.3	175.1	.39	1679.6	137.3	.16	3291.1	1.42	36.0	-.39

DATA BASE SUMMARY

1971-1974

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	KEY MODES LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
31	402	215.8	6.87	94.3	97.6	.28	1248.8	83.6	.18	1847.2	1.35	44.5	-.45
32	413	388.4	7.77	30.4	308.4	1.70	1627.1	212.2	.81	2776.0	1.33	-.7	1.11
33	373	138.6	2.75	72.6	174.2	1.95	1612.7	117.4	1.03	2619.5	1.32	9.0	1.40
34	389	334.1	8.69	70.2	372.3	2.34	1264.5	209.4	.21	3142.8	1.27	13.3	.04
35	447	166.5	4.29	61.5	104.2	.99	558.1	127.3	.77	2994.5	1.26	13.1	1.01
36	417	273.6	3.71	68.6	182.3	.36	1862.8	136.5	.23	2513.3	1.23	3.2	-1.05
37	323	75.3	1.11	100.8	72.8	.37	2014.3	65.2	.77	2320.8	1.21	14.2	1.21
38	314	102.9	.17	97.0	118.9	.51	839.0	94.9	.95	1197.0	1.20	7.7	2.19
39	342	146.9	3.16	90.8	151.1	.51	2047.8	82.5	.13	2853.0	1.19	5.7	1.96
40	422	171.2	4.15	49.3	109.2	.70	1420.9	90.6	.97	2635.2	1.18	27.5	-.88
41	352	339.3	7.77	84.1	149.5	1.26	1779.2	130.2	1.19	2691.3	1.14	32.0	.76
42	394	248.9	1.31	203.8	101.3	.23	1048.8	92.9	.25	2099.8	1.13	13.7	-.29
43	374	171.0	1.19	146.0	232.1	.38	2605.3	144.2	.16	3443.3	1.08	9.9	3.22
44	379	601.3	4.05	32.0	138.2	.70	807.3	82.5	.14	2530.2	1.06	7.6	-1.12
45	400	57.9	.63	71.2	68.9	.68	1191.3	64.8	.12	2859.6	1.04	-4.0	1.19
46	370	190.8	1.66	119.1	217.2	1.81	1453.4	176.9	2.46	1655.6	1.03	3.2	1.56
47	332	298.5	7.67	88.9	302.6	2.86	924.5	159.6	.27	3425.0	.99	13.0	1.20
48	426	155.9	.11	222.9	124.9	.15	1246.0	101.1	.25	2458.9	.96	15.0	-.39
49	331	227.8	2.11	107.7	158.9	1.01	1124.2	102.6	.64	1860.9	.93	13.9	1.32
50	350	308.8	8.39	27.3	211.6	.59	1737.6	172.7	.61	2888.5	.92	15.8	.22
51	372	161.4	.82	427.5	113.2	.10	2720.0	120.2	.62	3425.1	.91	14.3	3.73
52	317	206.8	.63	217.8	180.2	.63	1476.9	116.7	1.18	1520.1	.87	12.6	-.19
53	376	600.4	1.73	87.0	184.2	.28	2601.4	172.9	1.11	3517.7	.85	7.1	2.14
54	340	168.8	5.25	38.6	198.4	.41	1853.5	184.3	.17	3922.8	.81	20.9	4.82
55	411	192.0	1.24	150.4	220.7	.78	1535.6	152.2	1.00	1870.6	.77	-3.8	.10
56	444	208.8	3.80	63.6	210.3	2.95	492.5	204.5	3.78	1309.3	.77	59.0	-1.13
57	425	157.2	1.54	91.9	121.0	.19	2008.3	85.2	.15	3216.7	.71	40.4	-1.18
58	315	183.5	.22	385.0	158.3	.41	1425.4	97.2	.51	1443.6	.70	3.8	1.13
59	377	273.4	1.71	49.9	223.1	1.23	419.5	194.5	.91	2019.9	.67	21.2	.52
60	341	120.9	1.80	88.6	63.5	.14	746.5	55.3	.16	3009.5	.66	12.3	1.22

DATA BASE SUMMARY

1971-1974

	VEH. NO.	IDLE HC (PPM)	IDLE CO (PERCENT)	IDLE NOX (PPM)	KEY MODES LOW CRUISE HC (PPM)	LOW CRUISE CO (PERCENT)	LOW CRUISE NOX (PPM)	HIGH CRUISE HC (PPM)	HIGH CRUISE CO (PERCENT)	HIGH CRUISE NOX (PPM)	EMISSION REDUCTION HC (GR/MI)	EMISSION REDUCTION CO (GR/MI)	EMISSION REDUCTION NOX (GR/MI)
61	397	109.8	.65	74.0	139.4	.21	3075.3	122.5	.48	3717.4	.65	.2	2.42
62	312	157.2	1.51	123.1	94.8	.23	1105.7	115.0	.27	2601.0	.64	12.9	-.66
63	305	133.4	.90	249.7	116.7	.44	1895.6	128.3	.44	3285.5	.62	2.9	0.00
64	365	187.4	2.28	88.5	157.1	.20	1707.3	146.1	.54	2311.8	.59	5.6	3.93
65	354	335.8	3.36	207.4	133.5	.15	1907.1	125.3	.18	3726.6	.58	-2.3	.74
66	358	394.5	8.07	51.5	300.4	4.11	339.3	205.1	1.25	2857.7	.57	-.0	-.41
67	383	91.7	.31	127.5	80.5	.12	1474.8	45.7	.12	2344.7	.55	34.9	-1.05
68	393	258.1	4.54	34.8	143.6	.35	1512.9	92.0	.20	2529.2	.55	29.3	-.63
69	324	388.3	7.32	49.2	198.3	.27	3811.0	154.2	10.23	2909.3	.55	12.5	.46
70	391	168.1	2.10	95.6	134.6	.25	2174.7	77.9	.14	2605.8	.54	46.6	-.73
71	421	242.3	5.97	57.0	154.5	.36	1825.7	125.6	.36	2626.3	.50	-16.9	1.73
72	432	154.6	.34	94.0	156.1	.31	963.6	147.4	.31	2542.2	.49	-2.5	-.94
73	303	247.5	.31	242.4	204.5	.65	1125.9	187.1	1.20	1172.7	.45	5.6	.35
74	319	289.4	1.72	140.6	208.8	.32	1393.7	94.3	.52	1227.1	.44	1.4	.59
75	380	503.1	8.78	27.0	344.2	2.72	1350.4	215.6	.83	3144.2	.39	.4	1.40
76	435	390.2	5.97	29.2	375.1	6.71	170.5	317.9	3.12	1668.3	.35	2.7	.51
77	371	202.5	4.06	57.4	131.3	.64	1006.0	107.3	.25	2652.6	.26	-.0	-1.06
78	419	239.2	4.51	48.8	145.7	.19	2037.2	142.8	.99	2440.3	.25	-4.3	.56
79	368	176.9	3.97	41.2	149.3	1.23	981.4	146.6	1.36	2832.7	.24	7.6	1.07
80	344	196.9	5.27	52.9	164.7	.53	865.2	180.1	2.59	992.6	.20	16.6	-1.40
81	318	57.8	.19	25.9	39.4	.41	352.2	59.2	.43	598.3	.18	9.8	-1.11
82	367	230.3	6.57	38.6	169.3	1.13	1705.8	155.2	.71	3111.0	.17	22.5	.07
83	429	158.8	1.50	66.9	142.5	.15	2564.4	151.2	1.13	3043.9	.17	.9	.30
84	387	278.2	8.82	27.8	153.7	1.12	1679.7	111.0	1.42	1748.4	.16	14.0	-.09
85	382	237.4	3.35	147.6	212.9	.38	2011.6	134.4	.17	3366.4	.12	4.4	-1.53
86	316	208.1	1.61	80.7	153.5	.25	1220.4	100.6	.73	1322.8	.12	-5.3	.22
87	410	193.0	5.83	73.4	151.6	.28	1457.1	92.9	.16	2148.7	.12	46.8	-.46
88	394	115.9	.48	266.9	110.5	.41	1677.0	106.5	.54	2678.7	.09	6.5	-1.78
89	431	240.0	1.30	140.9	202.9	.87	1661.4	182.3	2.01	1687.3	.03	18.4	.12
90	333	161.8	1.57	185.8	89.5	.65	530.1	69.3	.28	1414.6	.11	22.3	.94

APPENDIX B

7-MODE TO CVS CONVERSION

APPENDIX B

7-MODE TO CVS CONVERSION

To aid in converting the ARB 7-mode emission data to the Federal CVS 1975 cold standard, a set of regression equations relating 7-mode (hot) measurements to CVS measurements was developed using the TRW/CAPE-13 Data Base. The results appear in Tables B-1 through B-3. Since a consistent set of data with both 7-mode and 1975 CVS values was not available, the 1975 CVS figures were first derived from 1972 CVS measurements and then regressed on the 7-mode data. Thus, the regression results should be viewed as only a rough approximation to the actual 1975 CVS values. It should also be noted that the coefficient of determination, R^2, reported does not take into account differences between the actual 1975 CVS values and the derived values used in the regressions.

TABLE B-1 LINEAR REGRESSION RESULTS FOR 1975-CVS (COLD) EMISSIONS AS A FUNCTION OF 7-MODE EMISSIONS:

Pre-1966

REGRESSION ESTIMATE	R^2	SE
HC (1975) = 2.2213 + 0.8137 · HC (7 mode)	0.824	2.778
CO (1975) = 31.8547 + 0.9344 · CO (7 mode)	0.718	29.08
NOx (1975) = 1.0885 + 0.8181 · NOx (7 mode)	0.700	0.6978

Notes to Table:

R^2 is the coefficient of multiple determination. SE is the standard error of the estimate.

TABLE B-2 LINEAR REGRESSION RESULTS FOR 1975-CVS (COLD) EMISSIONS AS A FUNCTION OF 7-MODE EMISSIONS:

1966-1970

		REGRESSION ESTIMATE	R^2	SE
HC (1975)	=	2.6672 + 0.6806 · HC (7 mode)	0.544	2.209
CO (1975)	=	29.1285 + 0.9550 · CO (7 mode)	0.688	20.73
NOx (1975)	=	0.8116 + 0.8957 · NOx (7 mode)	0.760	1.249

Notes to Table:

R^2 is the coefficient of multiple determination . SE is the standard error of the estimate.

TABLE B-3 LINEAR REGRESSION RESULTS FOR 1975 - CVS (COLD) EMISSIONS AS A FUNCTION OF 7-MODE EMISSIONS: 1971-1974

REGRESSION ESTIMATE	R^2	SE
HC (1975) = 1.8119 + 0.691 · HC (7 mode)	0.541	1.031
CO (1975) = 24.9895 + 0.8017 · CO (7 mode)	0.613	19.08
NOx (1975) = 0.9787 + 0.8747 · NOx (7 mode)	0.725	1.079

Notes to Table:

R^2 is the coefficient of multiple determination. SE is the standard error of the estimate.

APPENDIX C

THEORETICAL TREATMENT OF EFFECTIVENESS-COST ANALYSIS

APPENDIX C

THEORETICAL TREATMENT OF EFFECTIVENESS-COST ANALYSIS

This appendix examines some of the theoretical aspects of the effectiveness-cost ratio used to calculate optimal rejection fractions. Basically, the effectiveness-cost ratio, EC, is nothing more than program effectiveness, pollution reduction, divided by program cost,

$$EC = \frac{\text{PROGRAM EFFECTIVENESS}}{\text{PROGRAM COSTS}} \tag{C1}$$

An "optimal"rejection fraction is one which maximizes this ratio.

Both program effectiveness and program cost can be expressed as a function of the rejection fraction R. The empirical evidence presented in Section 4.2 indicates that effectiveness and rejection are related as follows:

$$E = \alpha_0 R^{\alpha_1} \quad , \quad 0 < \alpha_1 < 1 \tag{C2}$$

where:

α_0 and α_1 are constants. Limiting α_1 causes the effectiveness function to exhibit diminishing returns, that is, increasing the rejection fraction causes a proportionately smaller increase in the effectiveness. The program cost function is:

$$C = \beta_0 (1+R) + \beta_1 \cdot R \tag{C3}$$

where:

β_0 and β_1 are constants representing fixed capital and operating costs and maintenance costs, respectively.

These expressions for effectiveness and cost may be substituted into (C1) giving:

$$EC = \frac{\alpha_0 \quad R^{\alpha_1}}{\beta_0 (1+R) + \beta_1 \cdot R} \tag{C4}$$

Differentiating with respect to R yields:

$$\frac{d\,(EC)}{d\,R} = \frac{(\beta_0(1+R)+\beta_1 \cdot R)\,(\alpha_0\alpha_1\ R^{\alpha_1 - 1}) - (\alpha_0 R^{\alpha_1})\,(\beta_0+\beta_1)}{(\beta_0(1+R)+\beta_1 \cdot R)^2} \tag{C5}$$

Setting (C5) to zero and solving for R yields the following expression:

$$R^* = \frac{\alpha_1 \cdot \beta_0}{(1-\alpha_1)\cdot(\beta_0+\beta_1)} \tag{C6}$$

Thus, the optimal rejection fraction will increase as the ratio of β_0 / $(\beta_0 + \beta_1)$ fixed capital and operating maintenance costs increases. R* also increases as $\alpha_1 \to 1$. The second derivitive of EC for R = R* yields a maximum under the constraints: $\alpha_0 > 0$, $0 < \alpha_1 < 1$ $\beta_0 > 0$, $\beta_1 > 0$

$$\frac{d^2(EC)}{d\,R^2}(R^*) = \frac{-\alpha_0\,\alpha_1^{\ \alpha_1 - 1}\ \beta_0^{\ \alpha_1 - 3}}{(1-\alpha_1)^{\alpha_1 - 4}\,(\beta_0+\beta_1)^{\alpha_1 - 2}} \tag{C7}$$

Consequently, the developed R* generates a maximum effectiveness cost ratio for the defined parameters.

APPENDIX D

EVALUATION OF EMISSION STANDARDS AT IDLE

APPENDIX D

EVALUATION OF EMISSION STANDARDS AT IDLE

Section 3.3 indicated some differences existed between the TRW and ARB data bases for idle emissions. In an attempt to further explore these uncertainties an analysis was performed on contrasting the impact of the developed standards (idle only) on resultant rejection levels. TABLE D-1 summarizes this analysis for the following three cases:

1) Application of the developed standards (idle only) to the TRW Data Base.
2) Application of the developed standards (idle only) to the ARB Data Base
3) Application of the ARB PVI standards to the ARB Data Base

The results for the first two cases reveal similar overall rejection levels(22.1 percent versus 19.4 percent) but show some inconsistencies at the disaggregate level (particular for Pre-1966 four cylinder vehicles). As noted earlier, the TRW Data Base had a limited number of these class of vehicles and consequently this segment of the data base was augmented,to some extent, with ARB data. The result for the third case indicates a somewhat higher rejection level (i.e., 30.0 percent) vis-a-vis the other two cases. This can be attributed directly to the higher rejection rates developed for six or eight cylinder vehicles (the rates for four cylinder vehicles appear consistant between cases two and three). Application of the developed standards yields a 20 percent rejection rate at idle and a 30 percent rejection rate using a loaded test (idle, low cruise, high cruise). The percent difference between the two does not provide a direct indication of the number of vehicle failing the loaded modes, since a number of them could also have failed idle. The reader is encouraged to review Table 4-16 for a modal distribution of rejection fractions.

In general, one can conclude that the variance in rejection rates for the three cases (approximately 10 percent) is well within the acceptable range accorded with the basic data measurements and processing. This indicates that the application of the developed standards should yield rejection levels at idle that are reasonably consistant with the PVI program and consequently the updating of the current PVI standards should produce only a small perturbation in that program.

TABLE D-1 COMPARISON OF REJECTION LEVELS FOR VARIOUS DATA BASES AND STANDARDS

Idle Only

AGE GROUP	TRW DATA BASE AND DEVELOPED STANDARDS			ARB DATA BASE AND DEVELOPED STANDARDS			ARB BASE SET AND ARB PVI STANDARDS		
	4 Cylinder	6 or 8 Cylinder	Total	4 Cylinder	6 or 8 Cylinder	Total	4 Cylinder	6 or 8 Cylinder	Total
55-65	71.4%	25.2%	27.3%	22.2%	17.6%	18.1%	23.3%	28.9%	28.5
66-70	41.7	18.4	20.3	30.5	23.0	24.3	33.1	34.7	34.4
71-74	41.4	14.1	19.5	16.2	13.6	14.6	12.3	30.8	24.2
TOTAL	45.8	19.5	22.4	21.6	18.4	20.0	21.5	32.3	30.0

* Standards Developed Using Limited ARB Data for Pre-1966 Four Cylinder Vehicles

APPENDIX E

DATA EVALUATION FOR IDLE CO RE-TEST STANDARDS

APPENDIX E
DATA EVALUATION FOR IDLE CO RETEST STANDARDS

Data on the following three tables were used in the evaluation of idle CO re-test standards. There is one table for each of the three pollutant species: CO, HC, and NOx. Ten candidate standards, in terms of percent idle CO, have been evaluated for each control type. These candidate standards are arranged in columns in each of the following tables, along with the reduction in vehicle emissions in tons per day (increase in emissions for the NOx table) to be expected as a consequence of the implementation of the standard. The figures at the bottom of each column give the total reductions (increases) in emissions in tons per day and as percents of the total vehicle emissions. The total vehicle population for the South Coast Air Basin has been taken as five million.

TABLE E-1 REDUCTIONS IN FLEET EMISSIONS OF CO DUE TO CANDIDATE RE-TEST STANDARDS

CONTROL TYPE	IDLE CO STANDARDS (% CO) AND REDUCTIONS IN CO EMISSIONS (TONS/DAY)										
Pre-1966, 4 Cyl	Standard	9.00	8.56	8.11	7.67	7.22	6.78	6.33	5.78	5.44	5.00
	Reduction	1.46	1.87	2.28	2.68	3.09	3.50	3.91	4.41	4.72	5.12
Pre-1966, 6 & 8 Cyl	Standard	10.0	9.44	8.89	8.33	7.78	7.22	6.67	6.11	5.56	5.00
	Reduction	15.2	21.3	27.3	33.4	39.4	45.5	51.5	57.6	63.6	69.7
1966-1970, Air	Standard	4.00	3.78	3.56	3.33	3.11	2.89	2.67	2.44	2.22	2.00
	Reduction	16.7	18.6	20.4	22.3	24.2	26.0	27.8	29.8	31.6	33.4
1966-1970, non-air	Standard	7.75	7.12	6.48	5.84	5.20	4.56	3.92	3.28	2.64	2.00
	Reduction	17.7	42.6	67.8	93.0	118	144	169	194	219	244
1971-1974, 4 Cyl	Standard	7.00	6.33	5.67	5.00	4.33	3.67	3.00	2.33	1.67	1.00
	Reduction	35.7	62.3	88.5	115	142	168	194	221	247	274
1971-1974, 6 & 8 Cyl	Standard	7.00	6.33	5.67	5.00	4.33	3.67	3.00	2.33	1.67	1.00
	Reduction	193	248	305	363	420	478	535	593	650	708
Total Reductions (Tons/Day)		280	395	511	629	747	865	981	1100	1220	1330
Reductions as Percents of Total Vehicle Emissions		3.23	4.56	5.89	7.26	8.62	9.98	11.3	12.7	14.1	15.3

TABLE E-2 REDUCTIONS IN FLEET EMISSIONS OF HC DUE TO CANDIDATE RE-TEST STANDARDS

CONTROL TYPE	IDLE CO STANDARD (% CO) AND REDUCTION IN HC EMISSIONS (TONS/DAY)										
Pre-1966, 4 Cyl	Standard	9.00	8.56	8.11	7.67	7.22	6.78	6.33	5.88	5.44	5.00
	Reduction	.159	.204	.249	.293	.338	.382	.427	.482	.516	.560
Pre-1966, 6 & 8 Cyl	Standard	10.00	9.44	8.89	8.23	7.78	7.22	6.67	6.11	5.56	5.00
	Reduction	1.66	2.33	2.98	3.65	4.30	4.97	5.62	6.29	6.94	7.61
1966-1970, Air	Standard	4.00	3.78	3.56	3.33	3.11	2.89	2.67	2.44	2.22	2.00
	Reduction	.110	.122	.135	.147	.159	.171	.184	.196	.208	.220
1966-1970, non-air	Standard	7.75	7.12	6.48	5.84	5.20	4.56	3.92	3.28	2.64	2.00
	Reduction	.117	.281	.447	.613	.779	.946	1.11	1.28	1.44	1.61
1971-1974, 4 Cyl	Standard	7.00	6.33	5.67	5.00	4.33	3.67	3.00	2.33	1.67	1.00
	Reduction	.367	.640	.908	1.18	1.45	1.72	2.00	2.27	2.54	2.81
1971-1974, 6 & 8 Cyl	Standard	7.00	6.33	5.67	5.00	4.33	3.67	3.00	2.33	1.67	1.00
	Reduction	1.98	2.54	3.13	3.72	4.31	4.90	5.49	6.08	6.67	7.26
Total Reductions (Tons/Day)		4.39	6.12	7.85	9.60	11.3	13.1	14.8	16.6	18.3	20.1
Reductions as Percents of Total Vehicle Emissions		.643	.896	1.15	1.41	1.66	1.92	2.17	2.43	2.68	2.94

TABLE E-3 INCREASES IN FLEET EMISSIONS OF NOx DUE TO CANDIDATE RE-TEST STANDARDS

CONTROL TYPE		IDLE CO STANDARD (% CO) AND INCREASES IN NOx EMISSIONS (TONS/DAY)									
Pre-1966, 4 Cyl	Standard	9.00	8.56	8.11	7.67	7.22	6.78	6.33	5.88	5.44	5.00
	Increases	.076	.097	.119	.140	.161	.182	.204	.230	.246	.267
Pre-1966, 4 & 8 Cyl	Standard	10.00	9.44	8.89	8.23	7.78	7.22	6.67	6.11	5.56	5.00
	Increases	.795	1.11	1.42	1.74	2.05	2.37	2.68	3.00	3.31	3.63
1966-1970, Air	Standard	4.00	3.78	3.56	3.33	3.11	2.89	2.67	2.44	2.22	2.00
	Increases	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1966-1970, Non-air	Standard	7.75	7.12	6.48	5.84	5.20	4.56	3.92	3.28	2.64	2.00
	Increases	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1971-1974, 4 Cyl	Standard	7.00	6.33	5.67	5.00	4.33	3.67	3.00	2.33	1.67	1.00
	Increases	-.186	-.324	-.461	-.599	-.738	-.874	-1.01	-1.15	-1.29	-1.43
1971-1974, 6 & 8 Cyl	Standard	7.00	6.33	5.67	5.00	4.33	3.67	3.00	2.33	1.67	1.00
	Increases	-1.00	-1.29	-1.59	-1.89	-2.19	-2.49	-2.79	-3.09	-3.38	-3.68
Total Increases (Tons/Day)		-.315	-.407	-.512	-.609	-.717	-.812	-.916	-1.01	-1.11	-1.21
Increases as Percents of Total Vehicle Emissions		.0462	.0596	.075	.0893	.105	.119	.134	.148	.163	.178